A COMPARATIVE AUTECOLOGICAL STUDY OF BLACK SPRUCE, JACK PINE, LODGEPOLE PINE, AND HYBRID PINE FOR DIRECT SEEDING IN NORTHERN ONTARIO

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ABSTRACT

A COMPARATIVE AUTECOLOGICAL STUDY
OF BLOCK SPRUCE, JACK PINE, LODGEPOLE PINE, AND HYBRID PINE
FOR DIRECT SEEDING IN NORTHERN ONTARIO

By

David Arthur Winston

A series of laboratory and field experiments were performed to compare germination, survival and growth of jack pine (*Pinus banksiana* Lamb.), black spruce (*Picea mariana* (Mill.) B.S.P.), lodgepole pine (*Pinus contorta* var. *latifolia*) and a hybrid pine (*P. contorta* var. *latifolia* x *P. banksiana*) under a variety of soil moisture, soil fertility and field site conditions.

In a study to determine the cardinal temperatures for germination, jack pine seed germinated rapidly over a wide temperature range, from 15.6 C (60 F) to 32.2 C (90 F). Lodgepole pine and hybrid pine were more sensitive to temperature. Optimum germination of lodgepole pine was restricted to the range of 21.1 C (70 F) to 26.7 C (80 F).

Two greenhouse pot studies compared the growth of seedlings of the three species and hybrid pine in two soil types at controlled soil moisture and soil fertility levels. The two soils were obtained from an experimental field location near Manitouwadge, Ontario, which covered two sites, a moist upland black spruce site, and a dry upland jack pine site. Black spruce seedlings grew best at soil moisture levels near 1/3 atmosphere suction, but they did survive and grow at 10 atmospheres soil moisture suction. All pines produced greater top and root weight than black spruce at all moisture levels. Both jack pine and lodgepole pine appear better suited for growth on low moisture

content soils than either black spruce or hybrid pine. Increased growth of black spruce was obtained on soil from the moist site at fertility levels increased to those prescribed by Wilde (1958) as Grade B. Optimum growth of pines was obtained at a lower fertility level than black spruce.

Seed germination and seedling survival of the three species plus hybrid pine were evaluated in field seeding trials at Manitouwadge in 1971 and 1972. Black spruce seed germinated in both years and on both moist and dry site conditions. Stocking of black spruce seedlings was poor in the 1971 trial but attained a high (75 percent) level in the 1972 seeding after the first growing season. Soil moisture levels near field capacity, and careful seedbed preparation are the two major factors affecting black spruce seedling survival. Jack pine and lodgepole pine seed germinated well in both seeding trials, with stocking exceeding 80 percent. Neither soil moisture nor seedbed preparation were deemed as critical for these two species as for black spruce. Hybrid pine seed germination was low in both 1971 and 1972 seeding trials, but, germination of those seeded in 1971 increased in 1972. Jack pine seed germinated sooner than the other species in the 1972 trial, during a period of high soil surface temperature and this is partly due to the differences in species germination response to temperature. Screening of seedspots, to determine if rodents were present and destroying seed on the cutover, were inconclusive.

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By

David Arthur Winston

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VITA

David Arthur Winston

Candidate for the degree of
Master of Science

Biographical Note

Born: Stockport, Cheshire, England, September 13, 1946.

Married, wife, Helen; daughter, Elaine

Education:

University of Toronto, B.Sc.F., 1968

Michigan State University, M.S., 1973

Employment:

Present: Research Officer, Canadian Forestry Service, Canada Department of Environment, Great Lakes Forest Research Centre, Sault Ste. Marie, Ontario.

April 1968 - April 1969: Land Use Planner, Ontario Department of Lands and Forests, Recreation Inventory Unit, Richmond Hill, Ontario.

Organizations:

Canadian Institute of Forestry

Canadian Pulp and Paper Association

Xi Sigma Pi

Botanical Society of Sault Ste. Marie, Ontario

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The author wishes to dedicate this dissertation to his wife, Helen, who has struggled through with spirit and determination, while spending countless hours working on the research and thesis preparation.

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CHAPTER I

INTRODUCTION

The technique of direct seeding for forest regeneration is currently undergoing renewed interest and application throughout North America. Although direct seeding is not a new technique, and indeed is Nature's method of regeneration, planting of seedlings has been practised by forest managers, to the neglect of seeding.

Recently, several reports have been published, indicating a return to direct seeding. Scott (1970), Smithers (1965), McQuilkin (1965), Derr and Mann (1971) have reported on seeding trials and programs established in their respective areas.

Rising interest in seeding can be attributed to several economic factors. Most notable are the high cost of planting and the increased number of acres that are harvested annually with the advent of mechanical harvesting equipment. This requires a cheaper and faster method of regenerating the increased acreage.

Scott (1970) reports that seeding is now the recommended method for regenerating jack pine (*Pinus banksiana* Lamb.) in Ontario. However, even for this species, direct seeding sometimes results in unexplained regeneration failures. Seeding trials with black spruce (*Picea mariana* (Mill.) B.S.P.) in Ontario have usually been failures. Successful seedings of black spruce have been reported elsewhere, by van Nostrand (1971) in Newfoundland, Johnston (1971a) in Minnesota, and Marek[1)] in

1) Personal communication, Mr. G. Marek, Ontario Ministry of Natural Resources, Beardmore, Ontario.

Ontario following modified types of clear-cut and intensive site preparation. Presently in northern Ontario, the standard harvesting technique is to clear-cut large areas, necessitating the planting of seedlings in order to obtain satisfactory regeneration. Financial resources of the Provincial Government do not permit site treatment and the planting of desired species on every acre harvested. This results in an ever-increasing back-log of non-regenerated forest land.

The ability to obtain successful regeneration of black spruce and jack pine by direct seeding would provide a partial solution to Ontario's forest regeneration problems.

This study provides information on environmental and climatic factors which favor the germination and survival of black spruce and jack pine on clear-cut areas in the boreal forest of Ontario. It also evaluates the potential use of lodgepole pine (*Pinus contorta* var. *latifolia* Dougl.) and a hybrid pine, jack pine x lodgepole pine (*P. banksiana* x *P. contorta* var. *latifolia*) as possible substitutes for seeding on black spruce and jack pine sites in northern Ontario.

CHAPTER II

REVIEW OF LITERATURE

The effects on local environments of large clear-cut areas are well referenced. Johnson *et al.* (1971) summarize some of the most important ones, which, depending on the particular circumstances may be either beneficial or detrimental to regeneration or alternative land uses:

1. Abrupt increase in incident light which encourages proliferation of ground vegetation.
2. Increase in sunlight reaching soil surface layers.
3. Increase in soil surface temperatures depending upon the color and texture, often to levels lethal for germinating seedlings, and also contributing to drying effects.
4. Increase in soil temperatures below the surface by as much as 5 C (9 F).
5. Increase in wind speeds and turbulence.
6. Reduction in atmospheric humidity.
7. Reduction in minimum temperatures and frequently an increase in maxima.
8. Increased incidence of frost.
9. Penetration of frost more deeply into soil layers, with an increase in frost heaving and soil detachment.
10. More rapid snow melt.
11. More violent impact of rainfall and, until

vegetation becomes established, more rapid surface run-off.

12. Frequent increases in soil moisture and occasional water-logging.
13. Accelerated oxidation and breakdown of organic layers.

A large portion of Ontario is covered by the Boreal Forest Type (Figure 1). This consists of extensive stands of jack pine, black spruce, white spruce (*Picea glauca* (Moench) Voss), balsam fir (*Abies balsamea*) (L.) Mill), white birch (*Betula papyrifera* Marsh.) and poplar (*Populus* spp.) as single species or mixed species stands (Rowe, 1959). Broad site classification systems have attempted to delineate sites most favorable to the growth of several species but little investigation has been done on a microsite basis (Hills, 1959; Chrosciewicz, 1963).

In current direct-seeding practices in Ontario, jack pine is seeded on a variety of sites, from dry to moist, including many from which a black spruce crop has been harvested. Thus, future stands will be predominantly jack pine. The development of the pulp and paper industry in Ontario has been and still is based mainly on a supply of black spruce fibre. If the supply of black spruce is seriously reduced, it is conceivable that a multi-million dollar industry will also suffer, since fibre quality is the major factor in the competitive edge that the Ontario industry still retains. Thus, attempts to obtain successful seeding of black spruce as well as jack pine are very important to Ontario's economic future.

1. JACK PINE

In his summary of direct seeding projects in Ontario, Scott (1970) indicates that successful seeding of jack pine has been consistently obtained on a wide range of sandy sites when seedbeds were prepared. Unexplained failures, however, have occurred and the optimum site requirements for successful germination such as seedbed condition, and degree and extent of scarification, have not been determined. Other factors which have been studied to a limited extent for their effects on seeding success are: soil and air temperature, precipitation, season of seeding, frost, rodents, vegetation, soil moisture and nutrition.

Jack pine grows primarily on a variety of soils of the Spodosol order (Podzols). It is capable of growing on very dry coarse, and medium sands and on gravelly soils, but it also occurs on fine sands, sandy loams, loams, clay-loams, and on relatively thin soils over rock outcrop. Only rarely does it occur on poorly drained soils. Generally, maximum growth occurs on moist upland till slopes that vary in texture from fine sand to clay (Cayford *et al.*, 1967).

Jack pine is a pioneer species with high light requirements (Logan, 1966). Fire promotes the establishment of jack pine by removing vegetation, exposing mineral soil and causing its serotinous cones to open and release their seed. It frequently occurs as a mono-species and stands of extensive size grow on dry outwash sand plains.

Burning, to simulate wildfire effects on seedbeds, requires expert knowledge about the influence of weather on fire behavior in many types and conditions of slash, and experience in manipulating fire to achieve desired results. Prescribed burning has been used successfully elsewhere (Chrosciewicz, 1970; Beaufait, 1962) as a method of seedbed preparation, but has not yet received widespread approval in Ontario.

The common method of site preparation used in Ontario is mechanical scarification to expose mineral soil seedbeds or planting spots, but what constitutes the best seedbed remains controversial. Studies by Cayford (1958, 1963) and by Sims (1970) indicate that a mineral soil seedbed, prepared either mechanically or by burning, is generally very favorable for germination, whereas undisturbed litter and humus are very poor seedbeds. An unpublished study by Waldron[2)] showed germination and early survival to be similar, in years of above-normal precipitation, on three different seedbed types (mineral soil, mineral soil mixed with humus, and humus).

Beaufait (1960) found poor growth of young jack pine seedlings on micro-sites where the upper soil horizons had been removed, possibly due to a reduction in soil moisture-holding and nutritive levels. He noted that bare sand was cooler than burned-over or non-disturbed soil surfaces and this may be advantageous in preventing seedling dessication due to high temperatures.

Studies by Fraser and Farrar (1953) indicated that conditions favoring a high-moisture content surrounding the seed, such as a fine textured seedbed, watering, shading, and sowing beneath the surface, resulted in good germination, whereas, conditions favoring drought resulted in lower germination. Partial shade, provided by slash or snags can help considerably in creating moisture conditions favorable for germination.

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2) Noted in Cayford *et al.*, 1967, p. 8.

Sims (1970) and Chrosciewicz (1960) also found the best germination on moist sites, with germination decreasing as the soil moisture regime decreased.

Miller and Schneider (1971) have reported that partial shade and wind protection greatly increased germination of jack pine seed. Survival was improved significantly by shading but not by high soil moisture content nor by removal of vegetation competition. All of the latter treatments did, however, increase seedling growth. Fraser (1970a) and Ackerman and Farrar (1965) studied temperature requirements for germination of jack pine seed in the laboratory. Fraser obtained maximum germination in only seven days at temperatures from 21.1 C (70 F) to 32.2 C (90 F), and after 28 days, had similar germination from 15.6 C (60 F) to 35.0 C (95 F). Ackerman and Farrar found no difference in germination at 15.6 C (60 F), 21.1 C (70 F) and 26.7 C (80 F) under continuous light conditions. Fraser obtained little or no germination at temperatures below 10.0 C (50 F) or above 37.8 C (100 F) after 28 days.

Generally, jack pine is a pioneer species capable of establishing itself on a wide variety of sites including those with low nutrient and moisture conditions. It requires adequate moisture and temperature for germination and survival. Failures of seeding have been attributed to poor seedbed preparation, climatic extremes, seed depredation by birds and rodents, frost, competition from vegetation, insects and disease. Additional research is needed to examine seeding, both natural and artificial, under combinations of seedbed preparations and various nutritional values, and to determine the range of site conditions on which jack pine can germinate and survive.

2. BLACK SPRUCE

Traditionally black spruce has been regarded as a swamp and peatland forest species, and in Ontario most regeneration research has been carried out on such areas. However, it also grows in extensive pure and mixed stands, with a shorter rotation period, on well-drained upland sites. Delineation of sites suitable for black spruce regeneration has been inadequate as has the determination of the environmental requirements needed to achieve successful direct seeding.

Linteau (1955), studying black spruce in Quebec, found that it grew best on a moist loam or sandy loam soil. It is commonly found growing on shallow or deep sands, or gravel tills, and occasionally on moss caps over bedrock (Lafond, 1958). Black spruce is sparse or absent on very dry sites, but frequently succeeds jack pine on these sites, particularly if a black spruce seed source is available. Vincent (1965) concluded that most existing stands are of fire origin.

As previously mentioned, although successful seeding of black spruce has not been obtained in Ontario, it has in other areas of North America where harvesting techniques differ. Johnston (1971b) recommended burning of slash within a year after harvesting, followed by seeding of 250 M seeds per hectare (100 M seeds per acre) to obtain adequate stocking. On upland sites, he stressed that burning should be severe enough to expose mineral soil.

Richardson (1970) obtained adequate stocking on burned, cut-over, moist to very moist upland sites. Stocking was reduced on wet sites. The organic mantle was relatively thin (average depth 3.7 cm, 1.5 inches) providing a moist but not excessively wet seedbed with temperatures favorable for germination. He felt that because of the thin humus layer, seedling root systems were able to become established in or just above the mineral soil before the organic horizon dried out. He suggested that seeding must be done shortly after burning, as the humus material probably becomes dry and matted and unsuitable for retaining adequate moisture for germination. A cool and moist climate was considered more favorable for black spruce germination and survival than either a hot and dry, or a cold and moist one.

Several researchers have examined the effects of seedbed condition on germination and concluded that a seedbed's ability to retain moisture was most important (Place, 1955; Linteau, 1957; LeBarron, 1944). Vincent (1965) rated seedbed receptivity in order of priority as: 1) beds of slow-growing sphagnum mosses; 2) moist rotten wood; 3) mineral soil with a light cover of Polytrichum; 4) moist bare mineral soil; 5) litter; 6) beds of fast-growing sphagnum; 7) feather mosses, living and dead. He cautioned, however, that each may have disadvantages. For example, sphagnum moss growth may engulf seedlings; litter, and rotten wood often dry out leaving roots without adequate moisture supply. LeBarron (1944) found least seedling mortality due to heat on mineral and scarified soil, and most mortality on burned duff. However, growth was better on the duff, possibly due to a nitrogen deficiency where organic matter was absent. Place (1955) found that burned organic surfaces became very hot in sunlight, and this could cause a complete failure of germination.

LeBarron (1944) found that shade cast by slash is beneficial to germination and survival in dry seasons. Logan (1969) found optimum seedling growth at light levels above 45 percent of available sunlight, and extremely reduced growth at 13 percent light, indicating that daily exposure to full sunlight for even a short period is desirable for young germinates, since healthier, more developed seedlings are better able to withstand environmental stresses.

Fraser (1970b), in studies of cardinal germination temperatures for black spruce, found that seed provenance had a significant effect on germination at different temperatures, and that optimum temperatures for maximum germination differed by provenance. Optimum temperatures for seed from Ontario site regions 5E, 4E and 3E (Ontario, 1963) were 10.0 C (50 F) to 26.7 C (80 F), 15.6 C (60 F) to 21.1 C (70 F) and 15.6 C (60 F) to 26.7 C (80 F), respectively. Germination did not occur below 7.2 C (45 F) or above 35.0 C (95 F).

The best application of existing knowledge could improve the results of current black spruce seeding operations. However, additional research is necessary to determine optimum site requirements for germination and survival. Accurate climatic prediction would also permit timing of seeding operations to take advantage of favorable conditions.

3. EXOTIC SPECIES

The introduction of exotic tree species to several areas of the world, most notably Australia, has afforded these areas a rapidly growing timber crop. The slow growth, long rotation period, and difficulty in obtaining regeneration of native northern Ontario conifer species makes attractive the possibility of introducing exotic species to Ontario. Lodgepole pine and the hybrid pine are two conifers that may be satisfactory alternatives to jack pine and black spruce.

Jack pine and lodgepole pine are both species of the Boreal

Forest whose respective ranges overlap in several locations in Alberta. Considerable controversy still continues about the origin of the two species since they are similar in some physical characteristics and hybridize naturally (Moss, 1949). The two species either developed independently or one species is a diverging glacial refugia of the other species (Yeatman, 1967). Mirov (1956) and Critchfield (1957) have found that the major positive means of distinction is a biochemical difference; jack pine consists of α - and B-pinene, while lodgepole pine is mostly B-phellandrene.

Lodgepole pine (84 M - 352 M clean seed/kg) has a slightly larger seed than jack pine (156 M - 551 M clean seed/kg) (United States Department of Agriculture, 1948). By comparison, black spruce seed is minute with 738 M - 1123 M clean seed/kg.

The available literature contains little information comparing lodgepole pine and jack pine growth, yield or site requirements. A personal assessment by the author indicates that although lodgepole pine is capable of growing on most sites occupied by jack pine and black spruce, it does grow better than jack pine on moist sites. Some winter injury of lodgepole pine was observed by the author in frost pockets at Longlac, Ontario, and by MacHattie (1956) in Alberta.

Smithers (1961) summarized much of the available literature on lodgepole pine silvics, ecology and silviculture. Like other conifer species, lodgepole pine seed requires adequate moisture and moderate temperature for germination and survival. Ackerman (1955) found that mineral soil exposure by scarification was necessary to obtain regeneration of lodgepole pine. This is similar to the requirements of jack pine as previously described.

Moss (1949) described the locations and stands of naturally occurring hybrid pines in Alberta where jack pine and lodgepole pine inter-mix. The hybrids exhibit a wide range of characteristics in stem, foliage, cones, etc., that are commonly identified with one or the other parent. Although the possibility of superior hybrid progeny is always present, little investigation has been done to resolve it. Yeatman and Teich (1969) discuss some of the implications and importance of provenance selection for screening species and hybrids. They also mention the few breeding studies that have been initiated in Canada to investigate natural and artificial hybrids (jack pine x lodgepole pine). Yeatman and Holst (1972) have reported on the winter hardiness of natural and artificial hybrids, and jack pine provenances. The natural hybrid from Alberta crossed to Petawawa (Ontario) jack pine was found to have suffered little winter damage and compared favorably with local Ontario jack pine provenances. In a Lakes States study, Anderson and Anderson (1965) found lodgepole pine and hybrid pine to be more susceptible than jack pine to sweet fern blister rust.

The evidence for and against seeding trials using lodgepole pine and hybrid pine is inconclusive, and I feel that further research is warranted to determine their potential as substitutes for jack pine and black spruce.

4. SEED DEPREDATION

Rodent and bird repellents were developed for use in direct seeding and were employed extensively in the southern United States (Mann, 1968). The most successful of these was a combination of arasan, endrin and aluminium with a latex sticker. This combination was adopted for operational use in Ontario, but it has not been clearly established that rodents or birds present a threat to direct seeding in this province. Recent investigations by Radvanyi (1970) and Crouch and Radwan (1971, 1972) indicate that repellent treatments can reduce germination and may be more harmful than the rodent and bird depredation. Future research on seeding in Ontario should include determination of the extent and degree of rodent damage.

CHAPTER III

METHODS

1. ORIGIN AND COLLECTION OF SEED FOR USE IN EXPERIMENTS

Jack pine, lodgepole pine, hybrid pine and black spruce seeds were obtained in 1970-1971 from provenances within the 2000 to 25000 growing-degree-day range (Boughner and Kendall, 1959).

Lodgepole pine and hybrid pine cones were collected in June, 1970 from individual trees at Marlborough and Fox Creek, Alberta.[3)] Jack pine cones were collected in August, 1970 from two stands in Nimitz Township, Chapleau Forest District, Ontario. Cones from the two species plus hybrid pine were shipped to Petawawa Forest Experiment Station for seed extraction, cleaning and basic germination tests.[4)]

Black spruce seed, obtained in May, 1971 from the Ontario Department of Lands and Forests office at Manitouwadge, Ontario, had been extracted, cleaned and tested for germination at their Tree Seed Plant at Angus, Ontario, in 1970.

Based on initial germination tests at Petawawa, seeds from lodgepole pine tree #1, and jack pine stand #1 were selected for all future field and greenhouse tests, except for the experiment to determine germination at several temperatures. See Appendix A for details of seed origin and initial germination trials. Seeds used in this study were not treated with repellents.

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3) Courtesy, Mr. R. Ackerman, Northern Forest Research Centre, Edmonton, Alberta.

4) Courtesy, Mr. B.S.P. Wang, P.F.E.S., Chalk River, Ontario.

2. CARDINAL TEMPERATURES FOR GERMINATION

Three lodgepole pine populations, one hybrid pine population and two jack pine populations were tested to determine their optimum temperatures for germination, and the germination response at several controlled temperatures.

Seeds were randomly selected in 100-seed batches from individual seedlots, treated by flotation to eliminate empty seed, pre-treated to break possible dormancy by cold soaking in dilute H_2SO_4 for 36 hours at 2 C (35 F), surface sterilized to inhibit mould, and seeded on double layers of saturated germination paper in sterile petri dishes. The procedures used followed the format described by Fraser (1970a). Dishes for each species were allocated by random methods to constant temperature cabinets set at temperatures from 7.2 C (45 F) to 35.0 C (95 F) in 2.7 C (5 F) intervals and to shelves within these cabinets. Seeds received constant low level illumination. Germination was tallied daily for 28 days and seeds were tallied as germinates when radicles reached 2 mm (.08 inches) in length.

Species and temperature differences were analyzed by analysis of variance and Duncan's New Multiple Range techniques.

3. EXPERIMENTAL FIELD LOCATIONS

A. General

Field germination and survival of the four seedlots was assessed under two widely divergent conditions of soil moisture. Two experimental areas were located near Manitouwadge, Ontario, (approximately 49 N Latitude, 86 W Longitude) in the Central Plateau Section, B8, of the Boreal Forest (Rowe, 1959). Two field experiments were initiated in the areas; the first in 1971 and the second in 1972. The cover type prior to cutting on the 1971 area was jack pine (70 percent), black spruce (25 percent), white spruce, white birch and poplar. Sixty percent of the timber volume was black spruce on the 1972 area with lesser amounts of jack pine and poplar.

On each location, two sites were selected arbitrarily and called an upland dry site and an upland moist site. The former had originally supported a stand of jack pine; the latter, a stand of black spruce.

B. Soil-Site Description and Analytical Methods

Soil pits were dug and profiles described in each of the two field sites in both 1971 and 1972. A representative sample was taken from each horizon of each pit and placed in an individual plastic bag for transfer to the laboratory. In addition, a large bulk sample was removed, consisting of the A_1 (Ah), A_2 (Ae) and top 10 to 15 cm (3.9 to 5.9 inches) of the B_2(Bf) horizons.

The horizon samples and a sub-sample of each of the two bulk samples were transferred to the Great Lakes Forest Research Centre in Sault Ste. Marie, Ontario for nutritional analysis. A double check on nutrition levels of the two soil samples was obtained by sending sub-samples to the M.S.U. Soil Testing Laboratory.

Nitrogen was analyzed by the semi-micro Kjeldahl technique. Phosphorus was determined by using a Bray P_1 solution compared to standards in a colorimeter. Potassium was measured in a flame emission spectrophotometer and calcium and magnesium were analyzed in an atomic absorption spectrophotometer. The pH was measured using a pH meter with a 1:1 soil:water ratio. Organic matter was measured by loss on ignition (gravimetrically). An additional sub-sample of each bulk sample was analyzed for texture using a standard S.S.S.A. hydrometer technique (Black, 1965).

Vegetation assessments were made on both sites to determine major species returning after harvest. In addition, an assessment of dead mosses was done to aid in site classification.

The remainder of the 1971 bulk soil samples were transferred in sealed cans to Michigan State University. A soil moisture retention analysis was made at 1/10, 1/3, 1, 2, 10 and 15 atmospheres tension levels with standard pressure plate equipment.

4. GREENHOUSE POT TRIALS

A. General

Two greenhouse experiments were established to determine and compare the growth of young jack pine, lodgepole pine, hybrid pine and black spruce seedlings in the two field soil mixtures at: a) different soil moisture levels, and b) different soil fertility levels.

The bulk field samples were air dried and sieved through a 2-mm sieve. Styrofoam pots[5)] 22.5 cm (8.6 inches) high x 13.0 cm (5.1 inches) top diameter were filled with soil to obtain 96 pots of each soil type.

Forty-eight pots of each type were randomly selected for a moisture stress experiment and the remaining 48 of each type were assigned to a fertility study.

The two experiments were established in January, 1972 under greenhouse conditions of 21.1 C (±2) (70 F) temperature, and 16 hour

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5) Courtesy, Dart Container Co., Mason, Michigan.

light, with available sunlight supplemented by 2500 ft-c artificial light.

B. Soil Moisture Levels

The experiment was a completely randomized factorial design with four replications. Treatments were: four seedlots, two soil types (called moist and dry to indicate their site origin), and three moisture levels. Each pot of each soil was randomly assigned a moisture and species treatment and allocated a spot on the greenhouse bench.

In mid-January, 15 seeds of the assigned species were sown in each pot. Air-dried pot weight was obtained at this time and then the pots were soaked. On the tenth day after sowing, as primary needle initiation began, the best five seedlings in each pot were selected for retention and all other seedlings were removed. At this time soil moisture treatments were initiated. Treatments were based on the soil moisture retention studies and selected to represent low, intermediate and high levels of soil moisture stress at moisture levels equivalent to 1/3, 2 and 10 atmospheres (one-third atmosphere is hereafter referred to as field capacity; however, this may not be applicable in the field sites). Pots, based on weight, were allowed to reach the weight equivalent to a percent moisture content prescribed as a treatment level. Moisture recharge was done daily to return the pot to its predetermined weight. Water was added throughout the pot soil by a syringe needle which was supplied by an automatic pipette.

Pots were removed from the greenhouse on May 8, 1972 and the 16-week-old seedlings were extracted and measured as follows: 1) for each seedling; top height, and length of the longest root; 2) for all seedlings in a pot; top (including stem and needles) and total root oven-dry-weight; and 3) nutrient analyses of needles and roots.

Needles were analyzed for nitrogen with a semi-micro Kjeldahl procedure digesting in the presence of a mercury catalyst. Phosphorus was extracted using a nitric-hydrochloric acid procedure and was determined colorimetrically upon development of a phospho-molybdenum blue. Potassium, calcium and magnesium were determined by atomic absorption spectroscopy.

Total roots were analyzed using the above methods but only for phosphorus, potassium, calcium and magnesium.

C. Soil Fertility Levels

The experiment was a completely randomized factorial design with four replications. Treatments were: four seedlots, two soil types (called moist and dry to indicate their site origin), and three fertility levels.

Pot preparation, seed sowing and seedling selection were performed in a manner similar to the Soil Moisture Level experiment (4B). Soil fertility levels selected, based on assessment of nutrient levels, were: 1) control, 2) Grade C, a low level of nursery soil fertility satisfactory only for pioneer pines, and 3) Grade B, a moderate level of nursery soil fertility satisfactory for the majority of conifers.

The latter two treatments are levels recommended by Wilde (1958) as necessary in order to obtain healthy seedling growth. Nutrient solutions were mixed so that sufficient N, P and K could be added to each soil and fertility-level treatment combination to raise the level of NPK to the prescribed level. Solutions were added in three bi-weekly applications to the soil surface commencing three weeks after sowing. The soil in each pot was soaked throughout the experiment, but care was taken to avoid over-watering to a level that might cause leaching.

Pots were removed from the greenhouse on May 10, 1972; seedlings were removed and analyzed as described in 4B.

Results for 4B and 4C were analyzed by the variance method and Duncan's New Multiple Range test was used to test significance of treatment means.

5. EXPERIMENTAL FIELD SEEDING IN 1971 AND 1972, MANITOUWADGE, ONTARIO

A. 1971 Seeding

The experimental seeding in 1971 was completed on June 2, on the moist and dry sites (Figure 2) previously described. The seedbed was prepared by a Bracke scarifier-seeder (Bergman, 1971) pulled by a Timberjack wheeled skidder. The rotating teeth on the Bracke flipped over the upper 8 to 15 cm (3.2 to 5.9 inches) of the organic matter and soil horizons, exposing soil of the A_2 (Ae) and B horizons. Scalps were made at a spacing of 1.2 m (4 feet). At the time of seedbed preparation, the air was extremely hot and dry, and the soil was dusty (Figure 3).

The seeding experiment was designed as a completely random block with four replications. Each block was to contain four rows of 25 seedbed scalps per row. Each row was to be randomly assigned a species for seeding. This design was established in the moist site but had to be modified in the dry site due to an error by the tractor operator. Instead, two blocks were established, each block having four rows, each row having 40 to 50 scalps per row (Figure 4).

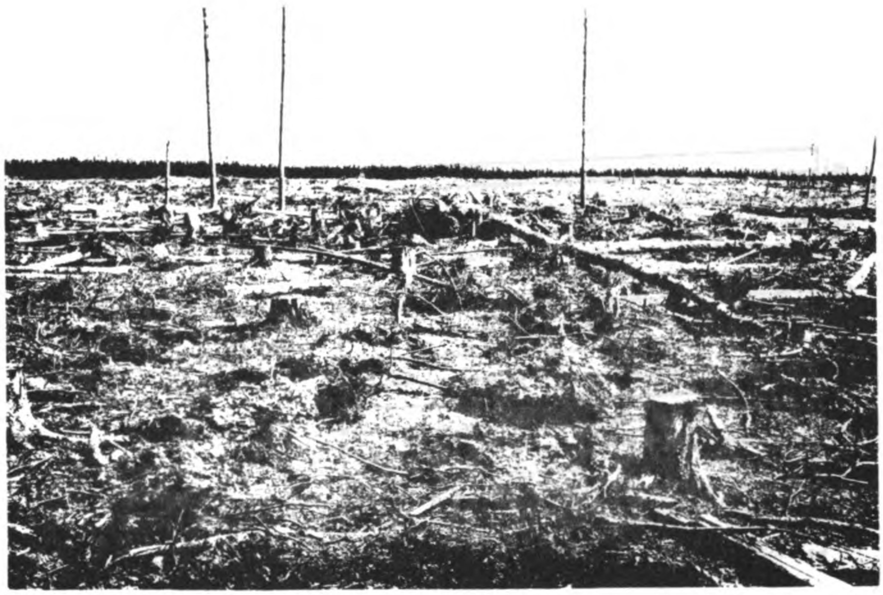

Figure 2. A general view of dry site cutover near Manitouwadge, Ontario.

Figure 3. Bracke scarifier-seeder pulled by Timberjack wheeled skidder, preparing seed spots on dry site skid road and cutover.

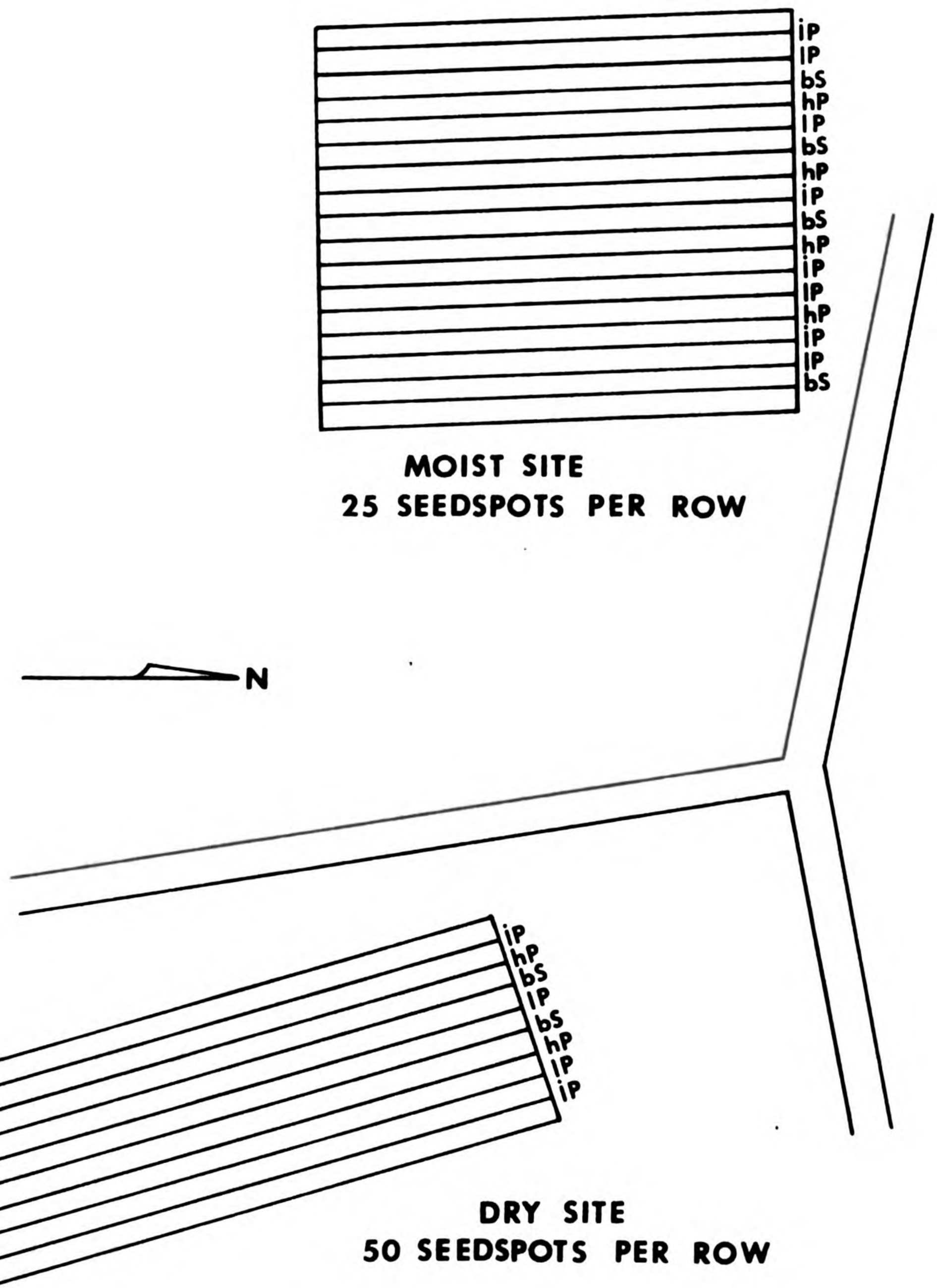

Figure 4. Schematic presentation of plot layout for 1971 seeding location. jP = jack pine, lP = lodgepole pine, hP = hybrid pine, bS = black spruce.

Seeding was done by hand using a bottle shaker obtained from the Ontario Department of Lands and Forests. Seed was shaken onto the exposed seedbed, and stepped on lightly to ensure seed-soil contact. Attempts to calibrate the seed shaker to release five to eight pine seeds or 9 to 12 spruce seeds were not very successful and the actual number of seed per scalp is unknown.

Soil temperature was measured and recorded by means of recording thermographs with 12.7-cm (five-inch) chromium-plated sensors that were placed on the soil surface. One thermograph was placed on each site, and seedbed temperature was recorded for the duration of the 1971 growing season.

Additional temperature and rainfall information for the area was obtained from the Manitouwadge Ontario Department of Lands and Forests office, approximately 24 km (15 miles) southwest of the experimental areas.

Germination was assessed periodically throughout the 1971 and 1972 field seasons. Seedlings on randomly selected scalps were excavated for measurement in late August, 1972.

B. 1972 Seeding

The 1972 seeding was established on sites similar to those selected in 1971 with all the four tree seedlots. It differed markedly in field procedure, and had an additional treatment, rodent protection, to determine if rodents influenced germination and survival.

The experiment was established as a random block factorial design with two replications. Treatments were: two sites, four seedlots, and two rodent prevention levels, (screened scalp, or non-screened scalp).

Each replication contained eight rows of 25 seedbed scalps per row. Scalps were located at 1.8 m (6 feet) intervals from a base line. All scalps were hand prepared by fire rake and mattock to ensure seedbed uniformity. Organic matter was removed to expose the A_1 (Ah) horizon and the latter material was mixed lightly with the underlying A_2 (Ae) soil.

Each pair of rows (one and two, three and four, five and six, seven and eight) within a block was randomly assigned a species for seeding. Then within a pair of rows, one of each pair of side-by-side scalps was randomly assigned a rodent protection treatment. This treatment consisted of a 45.7-cm (18-inch) conical-shaped mesh which completely covered the seed scalp. Thus, one of each pair of scalps was covered with a screen and the other was exposed (Figure 5).

Seeding was done by hand on June 25, 1972. Five seeds, of the species allocated to a row, were carefully placed in each scalp and stepped upon lightly. Screens were then placed over those scalps assigned to receive rodent protection.

Germination was assessed weekly. Colored toothpicks were used to mark individual seedlings as they germinated. A different color was used for each weekly period.

Detailed environmental observations were recorded from mid-June to early September, 1972 on both sites. Observation techniques and instruments used were as follows:

1. Temperature at the seedbed surface was measured at weekly intervals at nine randomly-assigned spots in each block, using a 24-gauge copper-constantan thermocouple (Fraser, 1968) connected

to a portable potentiometer. Temperature was measured at mid-afternoon.

2. Continuous recordings of the seedbed temperatures in each block were obtained by thermographs with 12.7-cm (5-inch) chromium-plated sensors placed on the soil surface.
3. Air temperature and relative humidity were continuously recorded using a Fuess hygrothermograph located on each site. Each hygrothermograph was placed in a standard Stevenson screen 114.3 cm (45 inches) above ground level.
4. Soil moisture content by weight was obtained twice weekly for the upper 5 cm (2 inches) of soil using gravimetric methods, for nine randomly selected seedbeds in each block.
5. Precipitation was measured by means of a standard Canadian 65.9-sq cm (10-square inch) rain gauge, at three locations per site. Rainfall was measured daily until September, then periodically until October.
6. Solar radiation was continuously recorded on each site by actinographs.

In late August, 10-week-old seedlings were excavated from several scalps in each site, washed and measured for top and root lengths.

jP	jP	bS	bS	hP	hP	lP	lP
o	x	o	x	x	o	x	o
x	o	o	x	o	x	o	x
x	o	x	o	o	x	o	x
x	o	x	o	o	x	x	o
x	o	x	o	x	o	o	x
o	x	o	x	o	x	x	o
x	o	x	o	o	x	o	x
x	o	o	x	x	o	x	o
o	x	o	x	o	x	x	o
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o	x	x	o	o	x	o	x
x	o	o	x	o	x	x	o
o	x	x	o	o	x	o	x
x	o	x	o	x	o	o	x
o	x	o	x	o	x	o	x
o	x	o	x	o	x	x	o
x	o	x	o	o	x	o	x
o	x	o	x	x	o	x	o
x	o	x	o	o	x	o	x
x	o	o	x	x	o	x	o
o	x	x	o	o	x	o	x
x	o	o	x	x	o	x	o

x - Scalped and seeded
o - Scalped, screened and seeded

jP = jack pine
lP = lodgepole pine
hP = hybrid pine
bS = black spruce

spacing: 1.8 m (6 feet) x 1.8 m (6 feet)

Figure 5. Example of independent randomly paired plot layout, 1972.

CHAPTER IV

RESULTS AND DISCUSSION OF EXPERIMENTS

1. SEED ORIGIN AND COLLECTION

Seed from the jack pine and hybrid pine collections were of relatively poor quality. Germination for the two jack pine seed collections averaged 75 percent and 63 percent and germination for the hybrid pine seed was only 60 percent. Lodgepole pine germination varied among populations, but all populations had significantly higher germination than both jack pine and hybrid pine. Black spruce germination was significantly better than all pine species. Details of initial germination tests for all species are shown in Appendix A.

2. CARDINAL TEMPERATURES FOR GERMINATION

A detailed summary of germination by population and temperature after 7, 14, 21 and 28 day periods is provided in Appendix B. A summary of mean percent germination by species for each temperature is found in Table 1. Table 1 includes a summary of germination results for black spruce from Site Region 3E adapted from Fraser (1970b). Figure 6 presents germination by species and temperature, 7 and 28 days after seeding.

Lodgepole pine and hybrid pine are both more temperature sensitive than either jack pine or black spruce. Both jack pine and black spruce seeds germinate quickly over a wide range of temperatures. The optimum range for jack pine germination was determined to be 15.6 C (60 F) to 32.2 C (90 F). Optimum black spruce germination was obtained by Fraser at 15.6 C (60 F) to 26.7 C (80 F), with acceptable

Table 1. Mean percent germination of jack pine, lodgepole pine, hybrid pine and black spruce* at different temperatures and days after seeding

Temperature C (F)	Jack pine				Lodgepole pine				Hybrid pine				Black spruce*			
	7	14	21	28	7	14	21	28	7	14	21	28	7	14	21	28
35.0 C (95 F)	52	54	55	55	16	30	39	47	2	4	6	8	12	31	33	38
32.2 C (90 F)	60	65	65	65	30	22	35	47	2	4	6	8	52	68	71	72
29.4 C (85 F)	72	73	73	73	14	20	27	31	7	8	10	11	64	78	82	85
26.7 C (80 F)	74	74	74	74	72	79	77	77	29	41	43	43	62	81	85	89
23.9 C (75 F)	67	69	69	69	62	69	70	71	30	37	38	38	53	77	86	90
21.1 C (70 F)	64	68	69	69	78	86	86	86	52	75	76	77	48	77	90	92
18.3 C (65 F)	63	72	73	74	19	72	74	75	3	73	74	75	51	80	92	93
15.6 C (60 F)	1	62	66	68	0	54	63	65	0	41	53	54	25	64	79	88
12.8 C (55 F)	0	32	58	62	0	4	6	8	0	0	9	11	0	47	72	86
10.0 C (50 F)	0	0	20	37	0	0	0	2	0	0	0	1	0	10	52	72
7.2 C (45 F)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	29

* Adapted from Fraser (1970b)

Outlined temperature zones denote optimum germination temperature range by species.

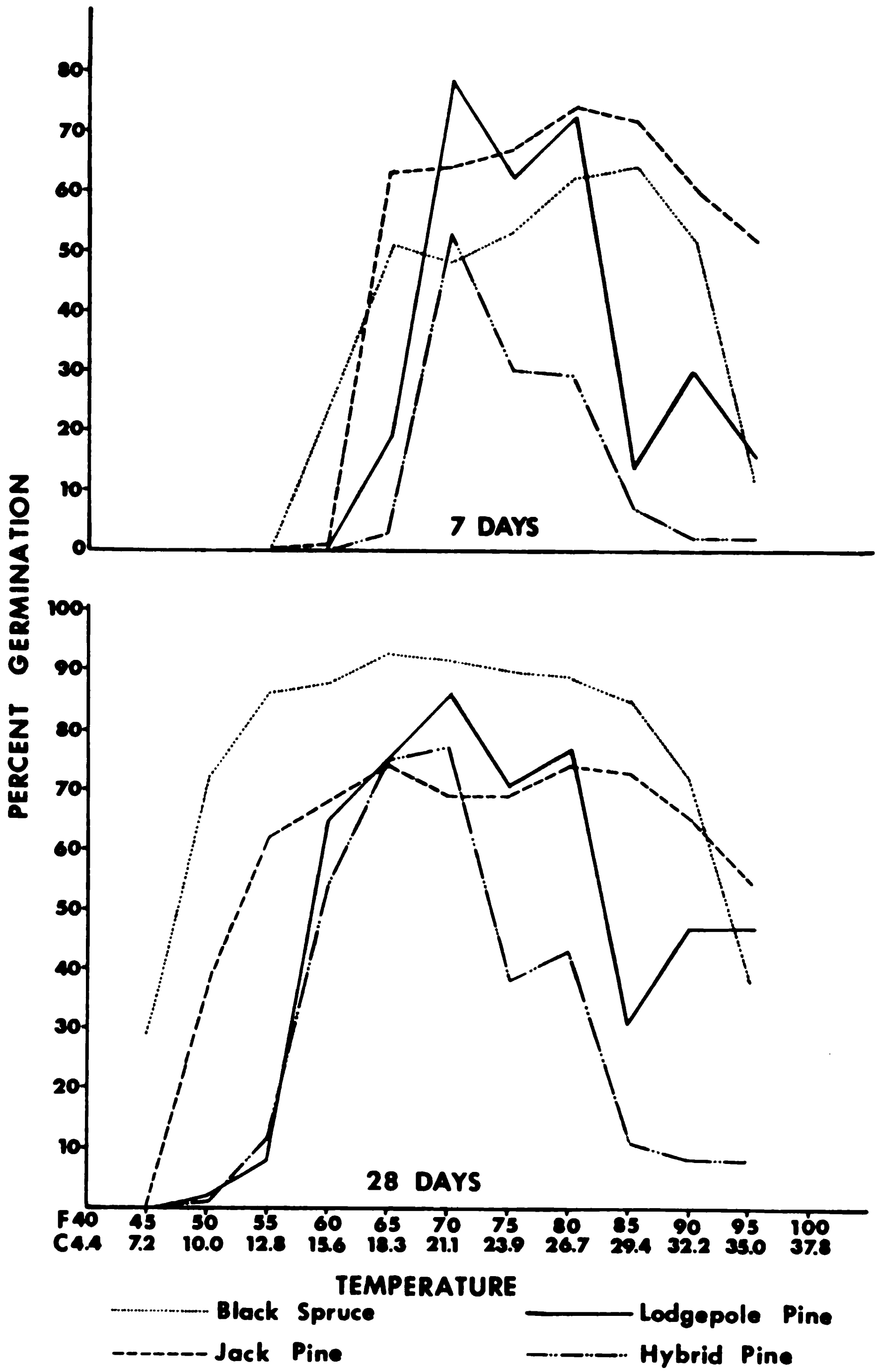

Figure 6. Mean seed germination for three species plus hybrid pine at several temperatures, 7 and 28 days after seeding.

germination still obtained at the extremes of 32.2 C (90 F) and 10.0 C (50 F). Lodgepole pine germinated rapidly at temperatures in the range 21.1 C (70 F) to 26.7 C (80 F), but was delayed at 18.3 C (65 F) and germination was reduced at all other temperature levels. Optimum temperature for germination was 21.1 C (70 F). Hybrid pine germinated rapidly at only one temperature, 21.1 C (70 F), and attained maximum germination at only 18.3 C (65 F) and 21.1 C (70 F). Germination levels for hybrid pine were 17 percent higher in the cardinal temperature experiment than in the initial germination test. This is possibly due to after-ripening of immature seed during the time lapse between the initial tests and subsequent cardinal temperature studies. All populations of lodgepole pine show a significant reduction in germination at 23.9 C (75 F). This can only be attributed to a species germination characteristic.

Results obtained for jack pine agree with those reported by Fraser (1970a) and by Ackerman and Farrar (1965). Optimum germination from lodgepole pine seed (86 percent in 28 days, Table 1) agrees with results obtained by Ackerman and Farrar (1965) for this species (88 percent in 21 days at 21.1 C (70 F)). However, they also obtained germination at "alternating 15.6 C (60 F) and 26.7 C (80 F), and 15.6 C (60 F) constant for four days followed by 32.2 C (90 F) constant for the remainder of the test", and suggested that a two-stage germination process might be necessary. The first stage requires temperatures in the 15.6 C (60 F) to 21.1 C (70 F) range, while the second stage requires temperatures of 21.1 C (70 F) to 32.2 C (90 F). Alternating temperatures were not used in this study. While constant temperature studies provide valuable information on species seed characteristics, further studies should be initiated to simulate field temperatures which fluctuate from 23.9 C (75 F) to 35.0+ C (95+ F) during the day and from 1.8 C (35 F) to 12.8 C (55 F) at night, during the growing season.

3. SOILS AND VEGETATION AT FIELD LOCATIONS

The soils are Spodosol (Podzol) sand tills, several feet in depth with a thin 5 to 10 cm (2 to 4 inch) organic mantle. Individual horizon characteristics are detailed in Table 2 and chemical properties are presented in Table 3.

All soils studied were acidic. The soil pH was higher in moist sites (5.9) than dry sites (3.6) and increased with soil depth (Table 3). The pH values obtained for the bulk samples are slightly higher than the horizon sample levels. This may be due to a several month delay in measurement of pH for the bulk samples. The nutrition levels determined for the bulk samples were confirmed by the M.S.U. Soil Testing Laboratory.

Textural analysis of the bulk soil samples indicate sand contents greater than 75 percent in soils from both moist and dry sites. Silt content was slightly higher in moist site soils (Table 4).

Results of the soil moisture retention studies are found in Table 5. The moist site soil has a higher moisture content at all tension levels (Figure 7). This can be attributed to its higher silt and organic matter content compared to the dry site soil.

Ground vegetation at the time of seeding was minimal. Logging slash and needle litter formed a heavy layer over much of the cutover. The major moss species on the moist site was *Pleurozium schreberi*

Table 2. Detailed soil pedon description for Manitouwadge moist and dry sites

Moist site soil

Classification: Typic Cryorthod* (Orthic Humo Ferric Podzol)**

Horizon	Depth (cm)	Description
L-F	5.0- 2.5	Raw to fermented litter.
F-H	2.5- 0.0	Raw to fermented litter.
A_1 (Ah)	0.0- 3.0	Black organic matter, sand (7.5 YR 2/0). Abundant roots.
A_2 (Ae)	3.0-10.5	Grayish brown (10 YR 5/2) loamy sand. Abundant roots, friable when moist.
B_2 (Bf)	10.5-51.0	Dark brown (7.5 YR 4/4) sand. Occasional roots. Blocky structure, firm when moist.
C	51.0+	Light brown (7.5 6/4) sand and gravel. Hard and cemented. No roots.

Dry site soil

Classification: Haplic Cryorthod (Mini Humo Ferric Podzol)

Horizon	Depth (cm)	Description
L-H	3.5- 0.0	Mixture of raw to decomposed litter.
A_1 (Ah)	0.0- 2.5	Black (2.5 Y 2/0) sand and organic material. Abundant roots.
A_2 (Ae)	2.5- 7.0	Light brownish gray (10 YR 6/2) loamy sand. Discontinuous at intervals. Abundant roots. Friable when moist.
B_2 (Bf)	7.0-80.0	Dark yellowish brown (10 YR 4/4) sand. Fine texture, with iron concentrations. Firm when moist. Occasional roots.
C	80.0+	Very pale brown (10 YR 7/3) sand and gravel. Firm when moist. No roots.

* United States Department of Agriculture, 1960

** Canada Department of Agriculture, 1970

Table 3. Soil horizon chemical analysis 1971 seeding area

Site	Horizon	Total N (%)	P	K	Ca	Mg	Fe		Organic matter (%)	Cation exchange capacity (meq/100 g)
			ppm							
Moist	Duff	0.483	26.7	660.0	4460.0	420.0	0.2	5.80	53.13	33.00
	A_1 (Ah)	0.785	6.9	25.0	7710.0	520.0	0.3	5.84	51.20	102.68
	A_2 (Ae)	0.046	1.1	20.0	1310.0	100.0	0.2	5.92	1.30	9.46
	B_2 (Bf)	0.010	0.4	23.0	580.0	60.0	1.2	5.82	0.05	2.20
	C	0.004	2.6	19.0	360.0	30.0	0.7	6.47	0.00	1.81
Dry	Duff	0.643	18.5	430.0	2750.0	360.0	1.4	3.59	64.99	60.34
	A_1 (Ah)	0.189	2.2	1010.0	300.0	100.0	2.1	3.43	20.70	46.35
	A_2 (Ae)	0.019	1.5	310.0	50.0	10.0	1.4	3.69	0.86	4.00
	B (Bf)	0.021	1.4	50.0	60.0	10.0	5.4	4.61	0.22	2.70
	C	0.004	1.3	50.0	60.0	10.0	0.6	4.86	0.00	0.80

Table 4. Soil physical and chemical properties for moist and dry site bulk samples

	Texture (%)				kg/ha available					
Site	Sand	Silt	Clay	%N	P_2O_5	K_2O	Ca	Mg	pH	% O.M.
Moist	77	14	9	.166	13	65	4925	342	6.2	7.41
Dry	82	9	9	.041	25	53	172	29	5.1	2.74

Table 5. Soil moisture content (percent by weight) for moist and dry site bulk samples

Tension (atm)	Soil moisture (% by weight)	
	Moist site	Dry site
0.10	17.5	9.3
0.33	12.3	6.4
1.00	11.9	5.0
2.00	9.3	5.0
3.00	9.0	4.7
10.00	6.6	3.5
15.00	6.3	3.2

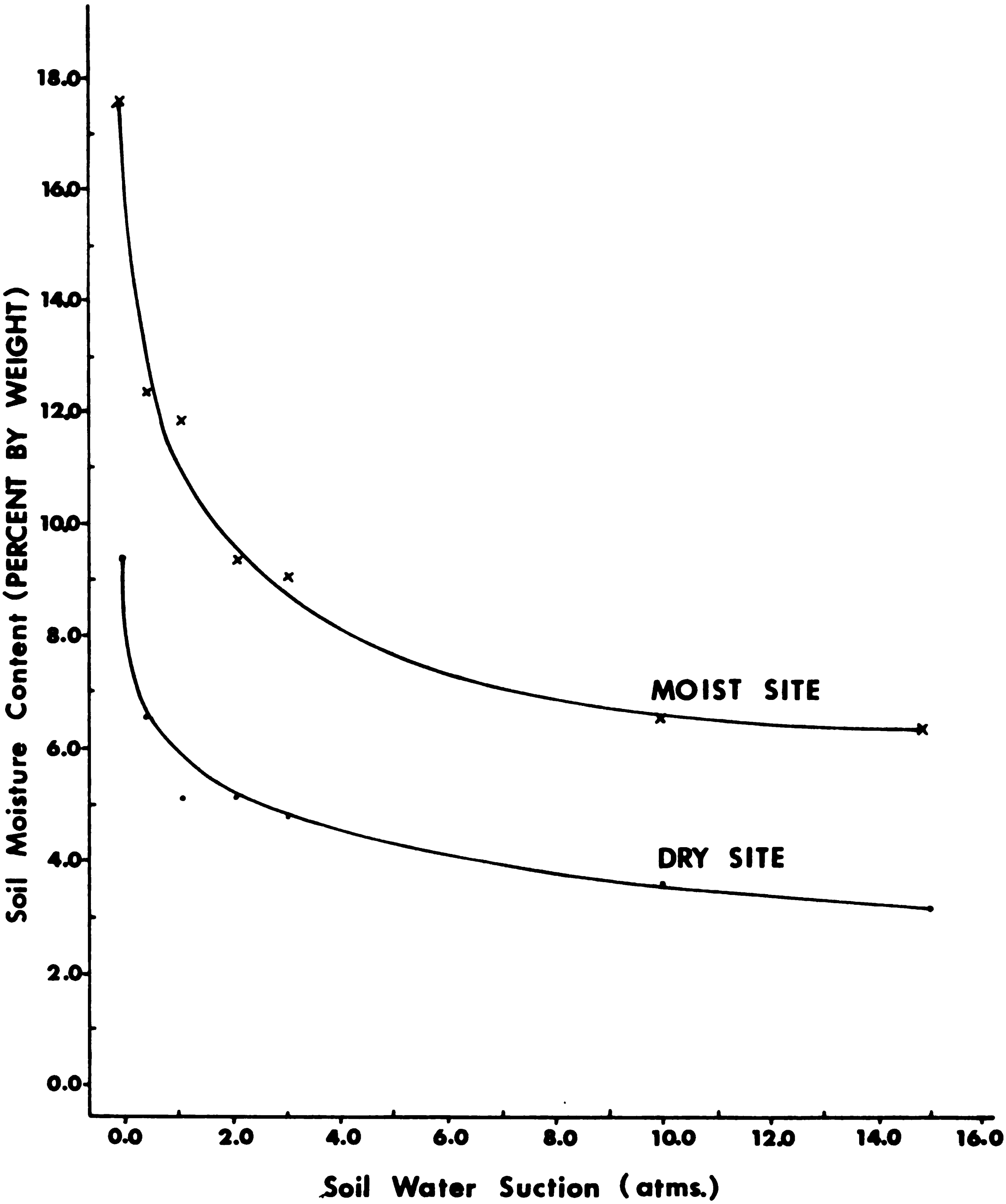

Figure 7. Soil moisture curves for bulk soil samples obtained from Manitouwadge, Ontario.

(BSG.) Mitt. with occasional patches of *Dicranum* spp., and *Hypnum crista-castrensis* Hedw. *Pleurozium schreberi* was again most frequent on the dry site. *Hypnum crista-castrensis* and *Dicranum* spp. were more frequent than on the moist site.

A vegetation survey in August, 1972 indicated considerable regrowth of vegetation on the moist site but very little on the dry site. Major plant species occurring in abundance on each site are as follows (not in order of frequency of occurrence);

Moist site: *Equisetum sylvaticum* L., *Fragaria virginiana* Duchesne, *Rosa acicularis* Lindl., *Epilobium angustifolium* L., *Cornus canadensis* L., and *Oryzopsis* spp.

Dry site: *Vaccinium* spp., *Rosa acicularis*, *Ledum groenlandicum* Oeder and *Salix* spp.

It should be noted that *Vaccinium* spp. were not observed on the moist site while *Fragaria virginiana* and *Oryzopsis* spp. were not found on the dry site.

4. GREENHOUSE POT TRIALS

A. Soil Moisture Levels

A detailed tabling of the results for the growth parameters measured for all treatments is presented in Appendix C. A brief summary and discussion is reported in the text.

1. Height growth: all species produced significantly greater height growth at 1/3 atmosphere; however, growth of lodgepole pine and black spruce in the moist site soil at 10 atmospheres tension was not significantly different than growth at field capacity. Site effect was only significant for black spruce grown in the moist site. Hybrid

pine and jack pine grown at field capacity in the moist site were significantly better than all other species, except for hybrid pine grown at field capacity in the dry site soil (Figure 8).

2. Length of the longest root: all species, except jack pine, produced significantly longer roots in the moist site soil than in the dry site soil. Lodgepole pine and hybrid pine produced significantly longer roots at field capacity than at other moisture levels, but there was no difference between the three pine species at field capacity. All pine species were significantly better than black spruce at field capacity on both the moist and dry sites (Figure 8).

3. Top weight: increased soil moisture content produced significantly greater oven-dry top weight for all species, except for lodgepole pine and black spruce at the two atmosphere level. The effect of site type varied from species to species. Black spruce did equally as well at 10 atmospheres suction as at two atmospheres, and in the dry site soil performed better at 10 atmospheres. It should be noted, however, that a few black spruce seedlings died at the 10 atmosphere, dry site treatment. This can be attributed to surface drying and resultant root dessication when roots were still developing.

Jack pine grown in the moist site at field capacity was significantly better than all other species at the equivalent treatment. Top weight production by lodgepole pine was considerably less than by the other pines except at the two atmosphere moisture level.

4. Total root weight: within treatment variation occurred and statistical analysis did not indicate any significant differences between treatments with one exception. Black spruce root weight was significantly lower than the pines at all moisture and site treatment

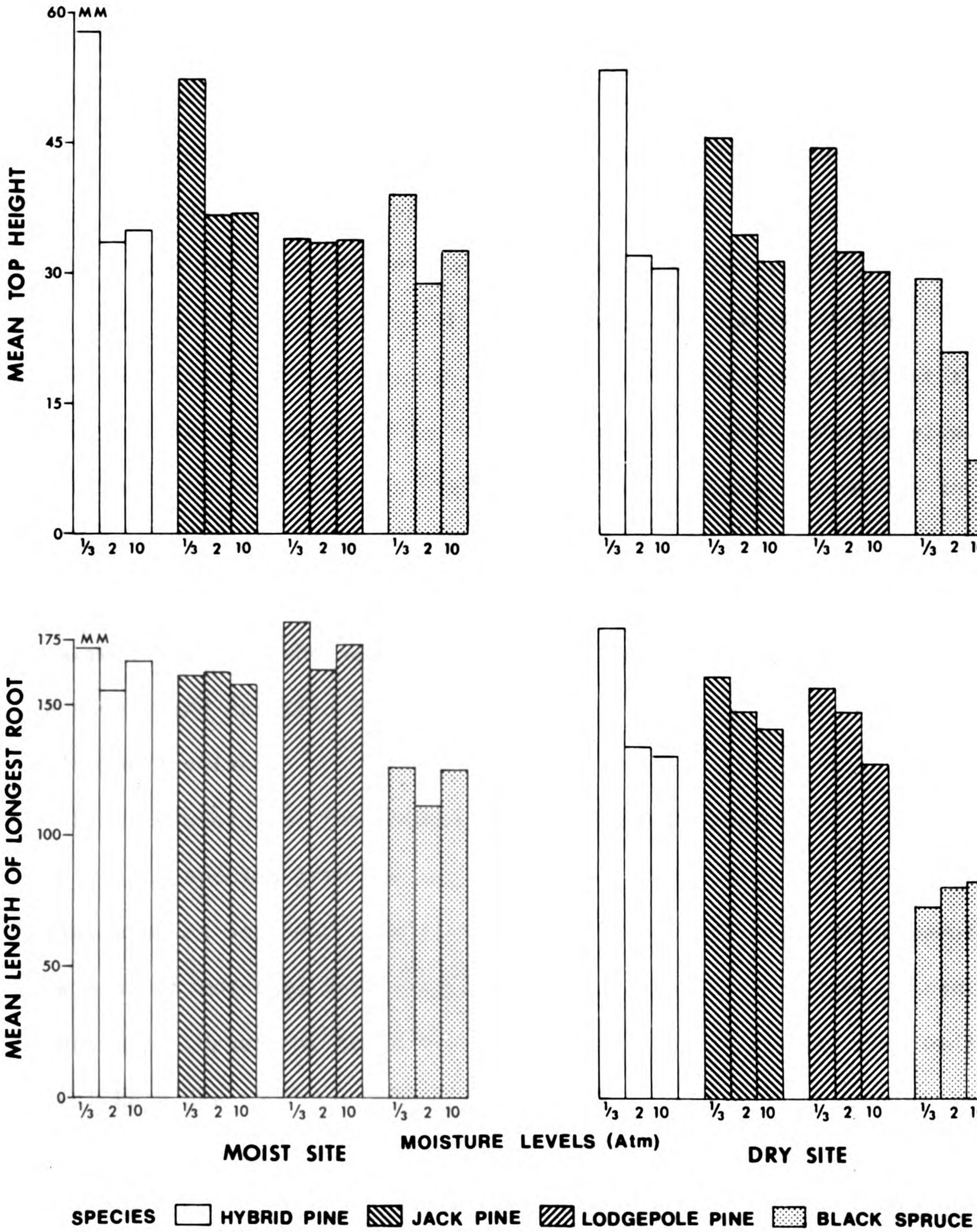

Figure 8. Seedling height growth and length of longest root at three moisture regimes for two sites.

combinations.

5. Chemical nutrient analysis of tops and roots: nitrogen concentrations were higher in seedling tissues of all species grown in the dry site than in the moist site. Concentrations of potassium and calcium were higher in both needles and roots of seedlings grown in the moist site than in the dry site for all species and moisture levels tested, with the exception of calcium in black spruce grown in the dry site soil at 10 atmospheres. The higher nutrient concentrations found in tissues of seedlings grown in the moist site soil reflect the higher initial values found in the analysis of the bulk soil samples. The higher concentrations in black spruce may indicate a tendency to accumulate calcium at the 10 atmospheres level.

There was considerable variation between replicates of a treatment for nutrient analysis. Values presented in Appendix C are means only and specific trends are difficult to define due to the variation involved.

B. Discussion of Soil Moisture Experiment Results

All species grew and survived on both the moist and dry site soils, even at soil moisture content near wilting point. Black spruce grew best at moisture levels above nine percent soil moisture content, by weight. Growth of black spruce was better in the moist site soil, most likely due to the higher level of available nutrients in this soil. Although generally assumed to be confined to moist sites, this study shows that when other factors are favorable, black spruce is capable of growing on dry site soils at moisture contents as low as 3.5 percent, by weight. Hybrid pine produced greater height growth and total tissue than either jack pine or lodgepole pine at field capacity.

These results indicate that if satisfactory germination of hybrid pine seed can be obtained, this species may be a suitable alternative to black spruce or the other pines for direct seeding on sites with soil moisture contents at or above 12 percent (field capacity).

Lodgepole pine produced less top growth and greater root growth than jack pine on the moist site soils. The greater root growth may increase lodgepole pine's ability to exploit a soil's nutrient and moisture supplies in the field, particularly during periods of environmental stress.

The results indicate that black spruce height growth is similar to lodgepole pine and jack pine at field capacity for the moist site soil; however, total fibre production (oven-dry weight) is considerably less.

C. Soil Fertility Levels

The nutrient levels prescribed by Wilde (1958) and utilized in this experiment as well as the necessary nutrient solutions formulated are found in Table 6. A brief summary of growth parameter results is presented in the text, while a detailed tabular presentation is found in Appendix D.

1. Height growth: increasing fertility from control to low effected a significant increase in height growth above that obtained in the control treatment level. Black spruce was the only species significantly increased by the increase in fertility level from low (Wilde's Grade C) to high (Wilde's Grade B) in the moist site soil. High fertility produced an unexplained reduction in black spruce height growth in the dry site soil. Black spruce grown in the moist site at the high fertility level produced significantly greater height

Table 6. Soil nutrient analysis and nutrient amendments required to increase soil fertility levels to treatment standards

		Nutrient standards			Nutrient increment			Prepared nutrient solution additions (2500 ml.)		
Treatments	Site	Total N (%)	Available P_2O_5 (kg/ha)	Available K_2O (kg/ha)	Total N (%)	Available P_2O_5 (kg/ha)	Available K_2O (kg/ha)	Ammonium nitrate (g)	Phosphoric acid (g)	Sulpho-mag (g)
Control	moist	.17	13	65						
	dry	.04	25	53						
Wilde Level C(1)	moist	.07	12	83	0	0	18	0	0	.38
	dry	.07	12	83	.03	0	30	.06	0	.64
Wilde Level B(2)	moist	.12	30.6	166	0	17.6	101	0	.24	2.09
	dry	.12	30.6	166	.08	5.6	113	.17	.11	2.36

(1), (2) From Wilde, 1958 (P. 360).

growth than jack pine and lodgepole pine but not hybrid pine. Growth of black spruce in the moist site was significantly greater than in the dry site soil at all fertility levels, despite the addition of nutrient solutions to bring the two soils to comparable levels of N, P and K. Pines grown in the moist site at control produced significantly better growth than in the dry site soil, but there was no difference in pine growth between sites at the low and high fertility levels (Figure 9).

2. Mean length of longest root: root length varied inversely with increased fertility level for all pine species except hybrid pine grown in the dry site soil. There was no significant difference among pines at comparable levels, but all pines had significantly longer roots than black spruce. Black spruce and hybrid pine were the only species that had significantly longer roots in the moist site. Black spruce was not significantly affected by increased fertility levels (Figure 9).

3. Top weight: the low fertility level (Wilde's Grade C) produced significantly increased top weight, compared to control, for all pines in both soils, except for lodgepole pine and hybrid pine in the moist site soil. Considerable variation occurred among black spruce treatments, resulting in no significant differences between sites or fertility levels despite the four-fold difference in mean weights between moist site and dry site soils at high fertility.

4. Total root weight: increased fertility had no significant effect on root weight of any species in the moist site, but was highly significant for all pines in the dry site. Both hybrid pine and jack pine root weights were significantly higher in the dry site than in

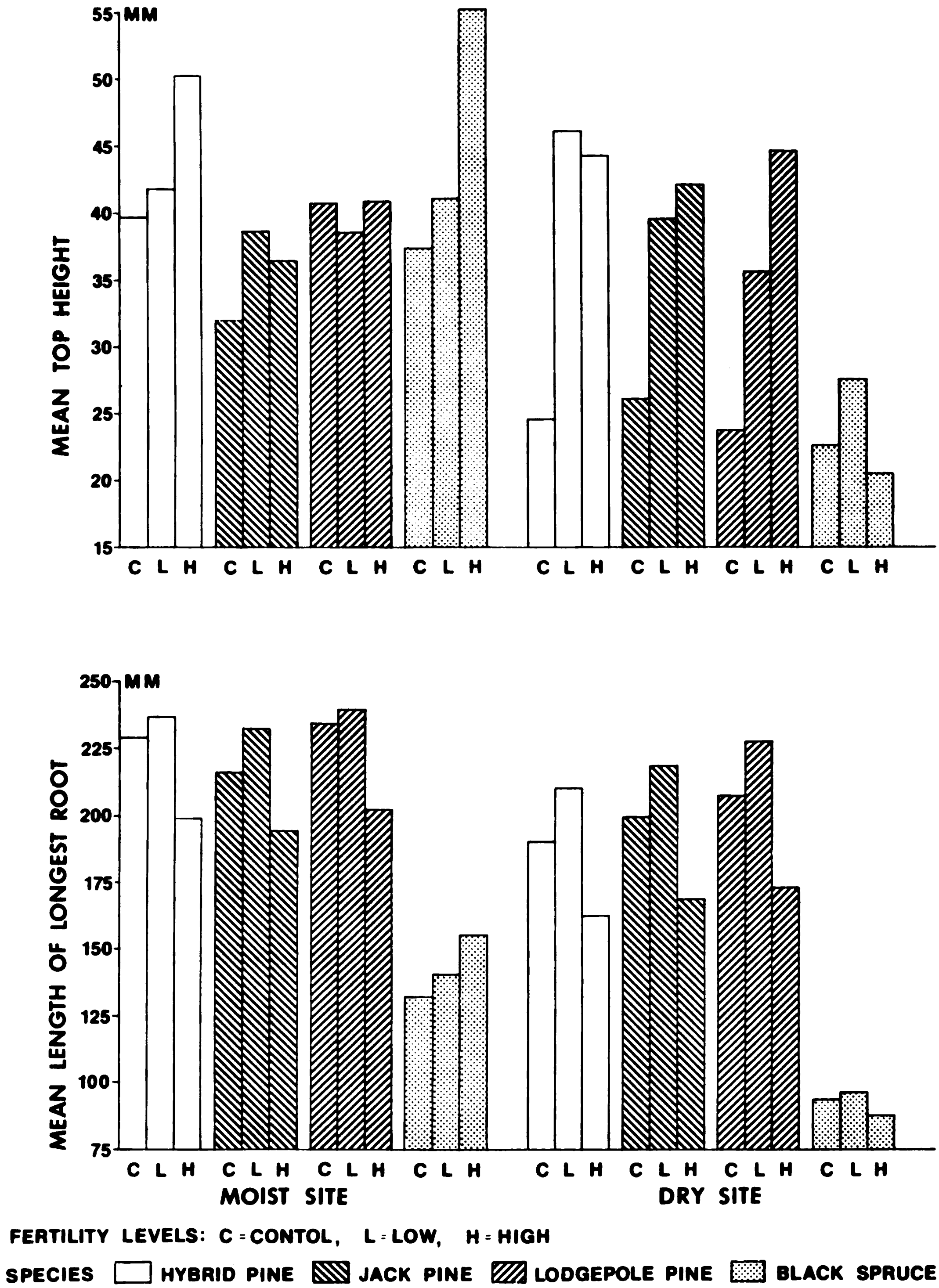

Figure 9. Seedling height growth and length of longest root at three fertility levels for two sites.

the moist site at the low and high fertility levels. Black spruce root weight was significantly lower than pine weight but no within-species treatment differences were obtained due to variation among replicates.

5. Chemical nutrient analysis of tops and roots: the roots of all species, when grown in the moist site soil, had higher concentrations of potassium, calcium and magnesium than when grown in the dry site soil. This difference was not found in top tissues. Potassium increased in both tops and roots for all species and sites with increased fertility level. All species, except jack pine, had higher levels of nitrogen in tops, for seedlings grown in the dry site at the high fertility level.

D. Discussion of Soil Fertility Experiment Results

In general, increasing fertility level, particularly for the dry site soil, resulted in increased height growth, top weight and root weight, and decreased length of longest root. Variation, among replications, for all measurements, obscured many differences for black spruce treatments. Height growth and root length, however, indicated superior development of this species in the moist site soil, particularly at high fertility. Conversely, the pines did not improve in growth as a result of increasing fertility levels from low to high. These results support Wilde's contention that black spruce grows better at his Grade B (high) fertility level than at Grade C (low), while pioneer species, such as pines, are capable of growing well at his Grade C nutrition level. There was very little difference in pine response to site at low and high fertility levels, but there was at the control level. The effect at control level reflects the basic differences in nutrient contents between the two soils. Particular attention should be paid to the increase in total root weight in all pine species grown at higher fertility levels in the dry site soil. This increase results from a larger root diameter and a greater number of rootlets (visual observation) and may be of value to field seedlings in increasing their ability to survive during environmental stress.

All pine species produced significantly greater oven-dry weight than black spruce at all treatments. The author feels that the differences exhibited between pines and black spruce, in the pot trials, are valuable for application and explanation of field survival of the species. Pines, being a more rapid developing species than black spruce, are able to withstand environmental stress whereas black spruce succumbs during early growth.

The fertility experiment indicates that little difference exists among the pine species tested, however, the raising of field soil nutrition levels to those prescribed by Wilde as Grade C, significantly increased total seedling weight of all pines. Black spruce height and root length were highest in the moist site soil, and height growth in this soil was significantly increased by raising fertility levels to Wilde's Grade B.

A comparison of foliage nutrient concentrations of jack pine, black spruce and lodgepole pine seedlings, to standards suggested by Swan (1970, 1972) indicates the following: potassium, calcium and magnesium at all treatments are in the range of sufficiency to luxury consumption. Nitrogen concentrations for jack pine and hybrid pine, grown in the dry site soil treatments, having levels of 1.20 to 1.50

percent, are in a transition zone of deficiency to sufficiency. All other species and treatments have levels above 1.50 percent; this is considered sufficient for good to very good growth.

Seedlings from both the soil moisture and soil fertility experiments were analyzed for phosphorus in addition to the nutrients previously mentioned. Chemical analysis results showed phosphorus concentrations to be acutely deficient in all treatments when compared to Swan (1970, 1972). No visible signs, such as foliage discoloration, were observed in either experiment and the cause for such low phosphorus results is unknown. It has been suggested[6)] that a chemical technique used in the extraction may not have removed all of the phosphorus available. Insufficient amounts of foliage sample remained to permit re-analysis of all pot replications; however, a grouping of four replicates did provide enough sample for re-analysis using a modified hydrochloric-nitric acid combination for extraction. The difference in techniques is presently undergoing thorough examination. Preliminary results indicate an approximate four-fold increase in phosphorus concentrations in the extraction. The concentrations are not reported in Table 22, Table 23, Table 28 and Table 29 because of the unreliable data obtained. All other nutrients and concentrations reported are valid.

E. Practical Importance of Soil Moisture and Soil Fertility Pot Trials

Black spruce was able to grow on both soils at 10 atmospheres suction, but grew significantly better at soil moisture levels above

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6) Personal communication, Mr. J. Ramakers, GLFRC, Sault Ste. Marie, Ontario.

nine percent, by weight. In the moist site soil, black spruce height growth was significantly increased by the raising of fertility levels to those of Wilde's Grade B. It is proposed that black spruce be seeded or planted on moist soils with fertility levels increased to that of Wilde's Grade B for significantly increased growth and seedling ability to withstand environmental stress. Hybrid pine was found to be the best of the pines for growth on the moist site soils (those sites commonly supporting black spruce). Jack pine and lodgepole pine grew well on both sites and are the best selection for regenerating dry site soils. It is recommended that fertilizers be added to the dry site soil to increase soil fertility to Wilde's Grade C level in order to take advantage of the increased number and size of roots in the pines.

A comparison of the two greenhouse experiments, Soil Moisture and Soil Fertility, is difficult due to the physical bench setup and different experimental procedures. In theory, the field capacity moisture level, with no fertilizer added, should be comparable to the control fertility level with adequate moisture. An examination of the results indicates considerable variation and possibly better growth in the moisture experiment. This can be explained by several possibilities: (1) the location of the experiments on the bench allowed one experiment to receive more sunlight than another, (2) the experiments were watered with tap water, (3) the moisture level of the fertility experiments was not as carefully controlled and may have been drier or wetter than desirable from time to time throughout the experiment.

Both experiments indicate that all species will survive and grow at low moisture levels, but all prefer conditions in the range of field capacity. All species appear to respond to increased fertility levels over those found in the field at Manitouwadge.

Recommendations based on these results would call for the seeding or planting of black spruce or hybrid pine on the moist sites, and jack pine or lodgepole pine at the drier range of moisture and on the dry sites.

5. RESULTS AND DISCUSSION OF 1971 AND 1972 FIELD SEEDING EXPERIMENTS

A. Results and Discussion of 1971 Seeding

Climatic data are presented for July to September, 1971 in Table 7. Data indicate the mean daily maximum and minimum soil temperatures at the experimental site and the air temperature at Manitouwadge for each weekly period in 1971. Rainfall values are total rainfall occurring for each weekly period.

Cumulative germinates, percent stocking,[7] and number of seedlings dead between assessment periods, based on the two year test period, are presented in Figure 10 and Figure 11 for the moist and dry sites, respectively. Statistical analyses were not performed owing to the lack of information on number of seed sown.

The total number of germinates per row of scalps indicates that more seeds germinated on the dry site than on the moist one. Despite this, stocking is high on both sites for all of the pine species. Black spruce, despite the high total number of germinates on the dry site, over a two year period, has a low percent stocking because mortality was also high. A comparatively low number of black spruce

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[7] A seedspot is said to be stocked when one or more seedlings are present.

Table 7. Weekly rainfall and air temperatures measured at Manitouwadge weather office, and field soil surface temperatures for July - September, 1971

	Soil temperature C (F)				Manitouwadge		
	Moist site		Dry site		Air temperature C (F)		Rainfall
Date 1971	Mean maximum	Mean minimum	Mean maximum	Mean minimum	Mean maximum	Mean minimum	cm (inch)
July 5-12	30+ (86.0+)	6 (42.8)	35+* (95.0+)	10-* (50.0-)	22 (71.6)	8 (46.4)	1.06 (0.42)
July 13-19	29 (84.2)	7 (44.6)	28 (82.4)	10- (50.0-)	20 (68.0)	8 (46.4)	7.34 (2.89)
July 20-26	25 (77.0)	8 (46.4)	33 (91.4)	10 (50.0)	19 (66.2)	10 (50.0)	3.53 (1.39)
July 27-Aug. 2	23 (73.4)	6 (42.8)	25 (77.0)	10- (50.0-)	16 (60.8)	6 (42.8)	2.22 (0.90)
Aug. 3- 9	30+ (86.0+)	10 (50.0)	34 (93.2)	12 (53.6)	26 (78.8)	9 (48.2)	0.00 (0.00)
Aug. 10-16	25 (77.0)	6 (42.8)	28 (82.4)	10- (50.0-)	19 (66.2)	7 (44.6)	2.81 (1.11)
Aug. 17-23	26 (78.8)	5 (41.0)	28 (82.4)	12 (53.6)	19 (66.2)	10 (50.0)	1.70 (0.67)
Aug. 24-30	26 (78.8)	12 (53.6)	32 (89.6)	10- (50.0-)	21 (69.8)	6 (42.8)	0.20 (0.08)
Aug. 31-Sept. 6	26 (78.8)	8 (46.4)	33 (91.4)	15 (59.0)	23 (73.4)	13 (55.4)	0.63 (0.25)
Sept. 7-13			30 (86.0)	11 (51.8)	19 (66.2)	9 (48.2)	3.27 (1.29)
Sept. 14-20	20 (68.0)	3 (37.4)	25 (77.0)	10- (50.0-)	15 (59.0)	3 (37.4)	0.78 (0.31)
Sept. 21-26	17 (62.6)	3 (37.4)	19 (66.2)	10- (50.0-)	13 (55.4)	3 (37.4)	2.79 (1.10)

* Range of thermographs restricted recording of upper and lower limits: 30+, 35+ indicate temperatures above 30 and 35 C. 10- indicates temperatures below 10 C.

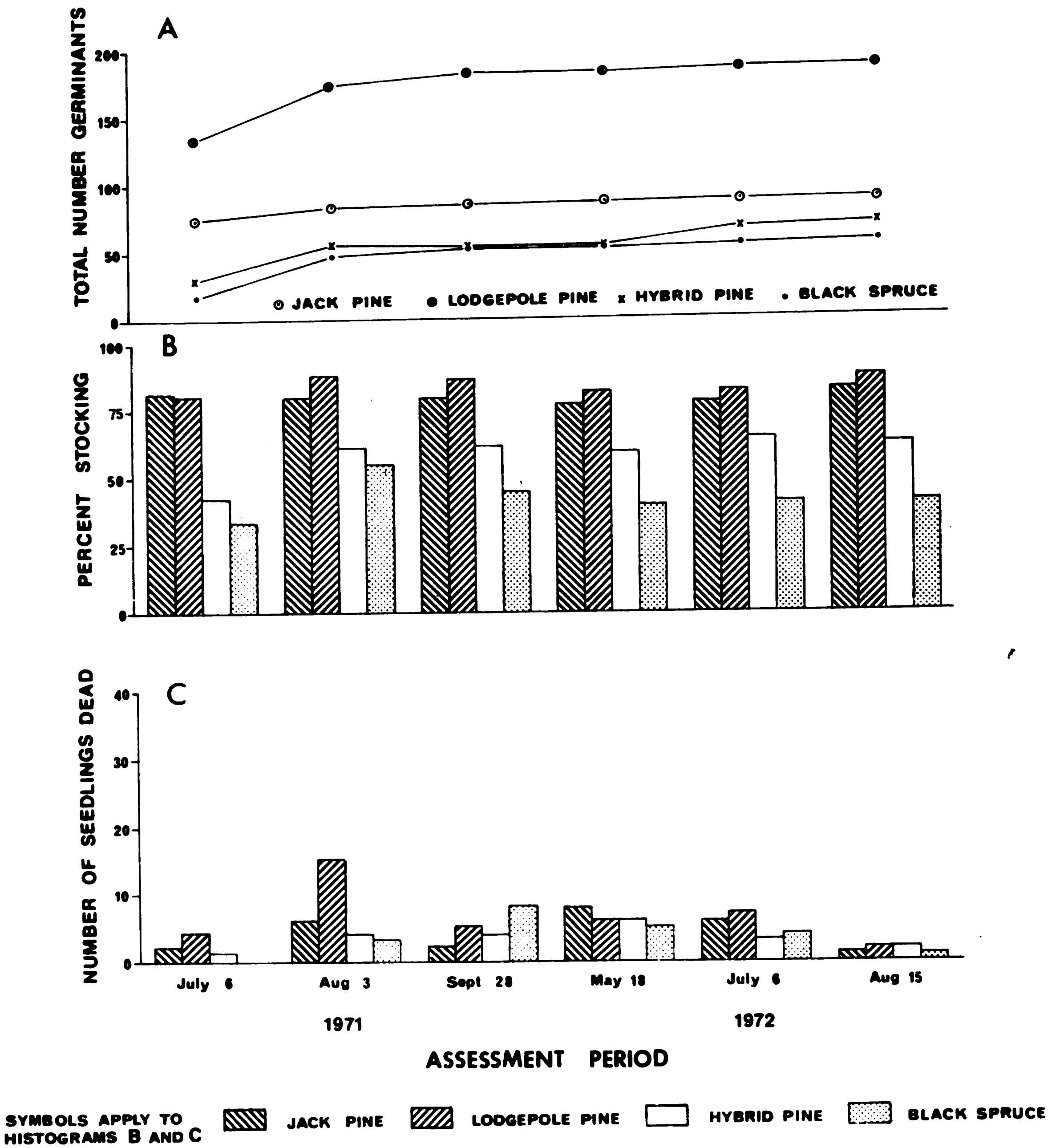

Figure 10. Germination, stocking and mortality for three species and hybrid pine seeded in 25 scalps on the moist site in 1971.

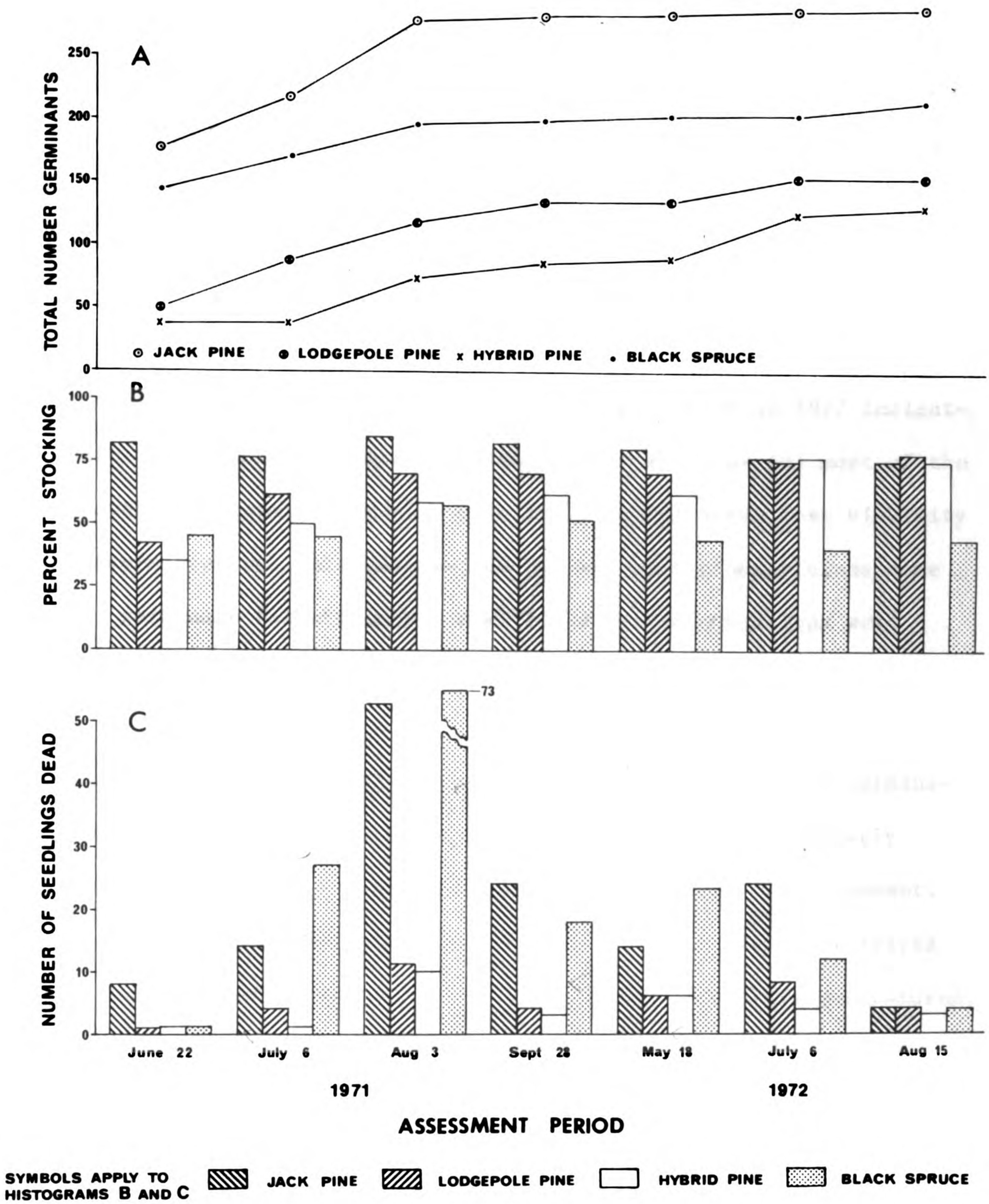

Figure 11. Germination, stocking and mortality for three species and hybrid pine seeded in 25 scalps on the dry site in 1971.

seeds germinated on the moist site yet mortality was low and stocking was similar to that on the dry site. Although portions of the moist site were extremely wet and at times scalps were flooded during 1972, stocking remained quite stable and mortality was low throughout 1972 for all species.

The number of hybrid pine germinates and stocking increased in 1972 after overwintering in the field. This tends to support the opinion that hybrid pine seed was immature as mentioned in the cardinal temperature study.

Only a few seed of the other species germinated in 1972 indicating that: (a) conditions were not favorable in 1972, or (b) most of the seeds capable of germinating did so in 1971, or (c) seeds lost viability during overwintering. Alternative (b) appears most plausible, as some seed did germinate (albeit only a few) in 1972, and conditions were favorable for germination of seed at various times in the 1972 seeding trial.

Most species germinated during July, 1971, with little germination occurring after the August 3, 1971 assessment date. Similarly most mortality occurred in late July prior to the August 3 assessment.

Mortality was extremely low over-winter. All species survived the harsh fall, winter and spring frosts, snow and freezing temperatures.

Both jack pine and lodgepole pine demonstrated an ability to germinate and survive on both moist and dry site conditions. A greater number of black spruce seed germinated on the dry site than on the moist site, despite higher moisture levels and slightly lower temperatures on the moist site. This may be partially due to variation in seed dispersal and is evidenced by the fact that several seeds germinated in one scalp while another scalp, with apparently similar seedbed conditions, failed to have any seeds germinate at all. The lack of germination could also be attributed to black spruce seed having more specific seedbed requirements for germination and survival than the pines. This appears to be particularly true for survival since mortality of black spruce seedlings was quite high and resulted in a low stocking level for black spruce.

Seedbed preparation by the Bracke scarifier-seeder was quite variable. Scalps were often too deep and too steep-sloped, which resulted in considerable washing. Many seedlings were semi-smothered by soil or had roots exposed by soil washing. Many spruce seeds may also have been buried and prevented from germinating, while the larger pine seeds were not buried, or at least not as deeply, and were able to germinate.

The Bracke scarifier-seeder appeared ideally suited to the cutover conditions of northern Ontario. Modifications to regulate scalp depth are necessary or potential savings which can be obtained by the use of the Bracke will be offset by the failure of seed germination and seedling survival.

B. Results and Discussion of 1972 Seeding

Weekly temperature means and precipitation are presented in Figure 12 and Table 8. Periodic measurements of soil temperature and soil moisture were obtained and results are presented as additional data in Appendix E.

Stocking, germination and mortality results (mean for all seed spots) are shown in Figure 13 and Figure 14 for the moist and dry sites. The effect of screening on germination is presented in Table 9.

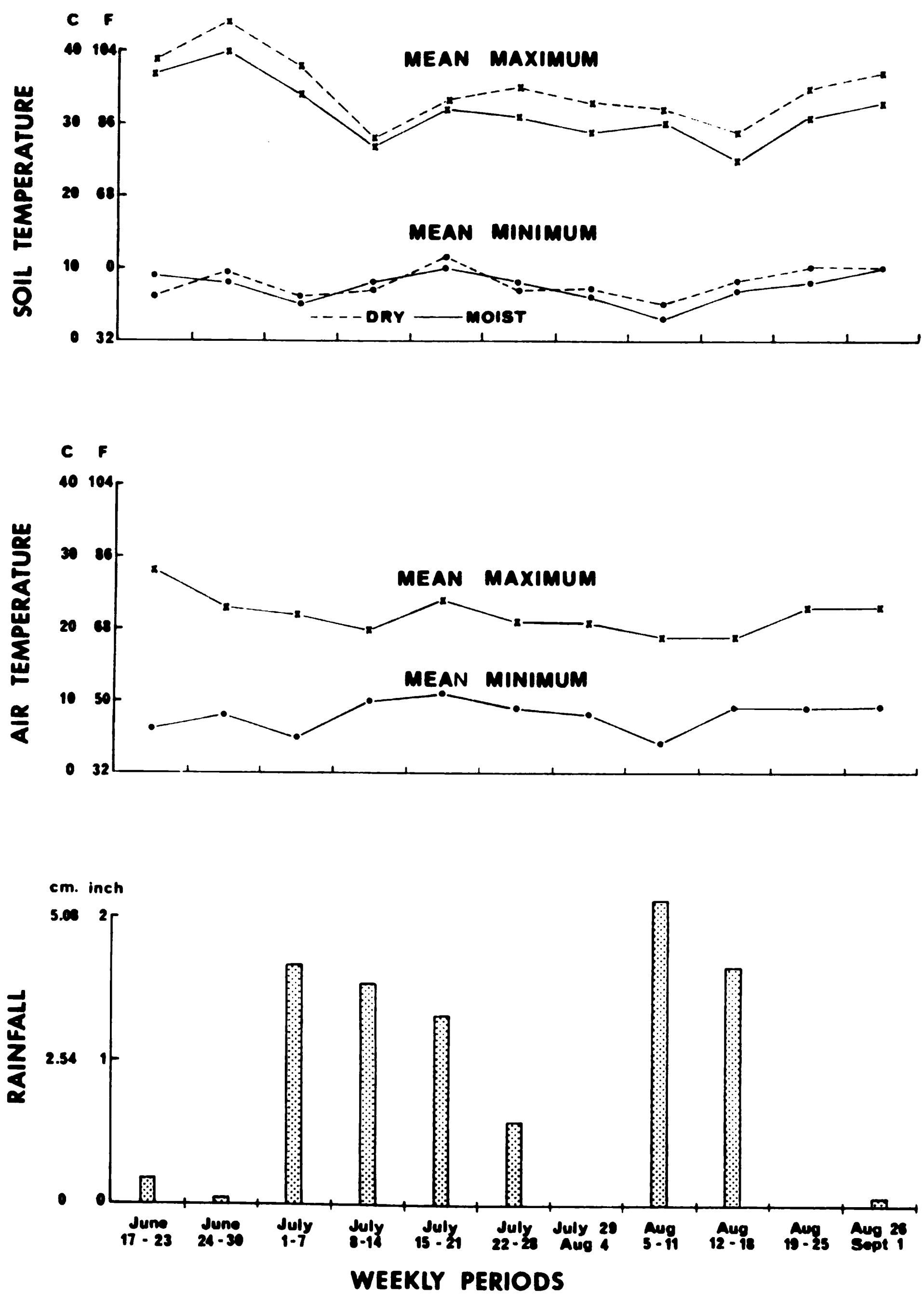

Figure 12. Mean soil and air temperatures, and total rainfall, by weekly periods for 1972 field seeding location.

Table 8. Soil and air temperatures, and weekly rainfall totals measured on the 1972 field sites

	Soil temperature C (F)				Air temperature C (F)		Rainfall
	Moist site		Dry site				
Date	Mean maximum	Mean minimum	Mean maximum	Mean minimum	Mean maximum	Mean minimum	cm (inch)
June 17-23	37 (98.6)	9 (48.2)	39 (102.2)	6 (42.8)	28 (82.4)	6 (42.8)	0.48 (0.19)
June 24-30	40 (104.0)	8 (46.4)	44 (111.2)	9 (48.2)	23 (73.4)	8 (46.4)	0.05 (0.02)
July 1- 7	34 (93.2)	5 (41.0)	38 (100.4)	6 (42.8)	22 (71.6)	5 (41.0)	4.24 (1.67)
July 8-14	27 (80.6)	8 (46.4)	28 (82.4)	7 (44.6)	20 (68.0)	10 (50.0)	3.91 (1.54)
July 15-21	32 (89.6)	10 (50.0)	33 (91.4)	11 (51.8)	24 (75.2)	11 (51.8)	3.32 (1.31)
July 22-28	31 (87.8)	8 (46.4)	35 (95.0)	7 (44.6)	21 (69.8)	9 (48.2)	1.49 (0.59)
July 29-Aug. 4	29 (84.2)	6 (42.8)	33 (91.4)	7 (44.6)	21 (69.8)	8 (46.4)	0.00 (0.00)
Aug. 5-11	30 (86.0)	3 (37.4)	32 (89.6)	5 (41.0)	19 (66.2)	4 (39.2)	5.35 (2.11)
Aug. 12-18	25 (77.0)	7 (44.6)	29 (84.2)	8 (46.4)	19 (66.2)	9 (48.2)	4.19 (1.65)
Aug. 19-25	31 (87.8)	8 (46.4)	35 (95.0)	10 (50.0)	23 (73.4)	9 (48.2)	0.00 (0.00)
Aug. 26-Sept. 1	33 (91.4)	10 (50.0)	37 (98.6)	10 (50.0)	23 (73.4)	9 (48.2)	0.07 (0.03)
Sept. 2- 9					17 (62.6)	3 (37.4)	
Sept. 8-30							12.34 (4.86)

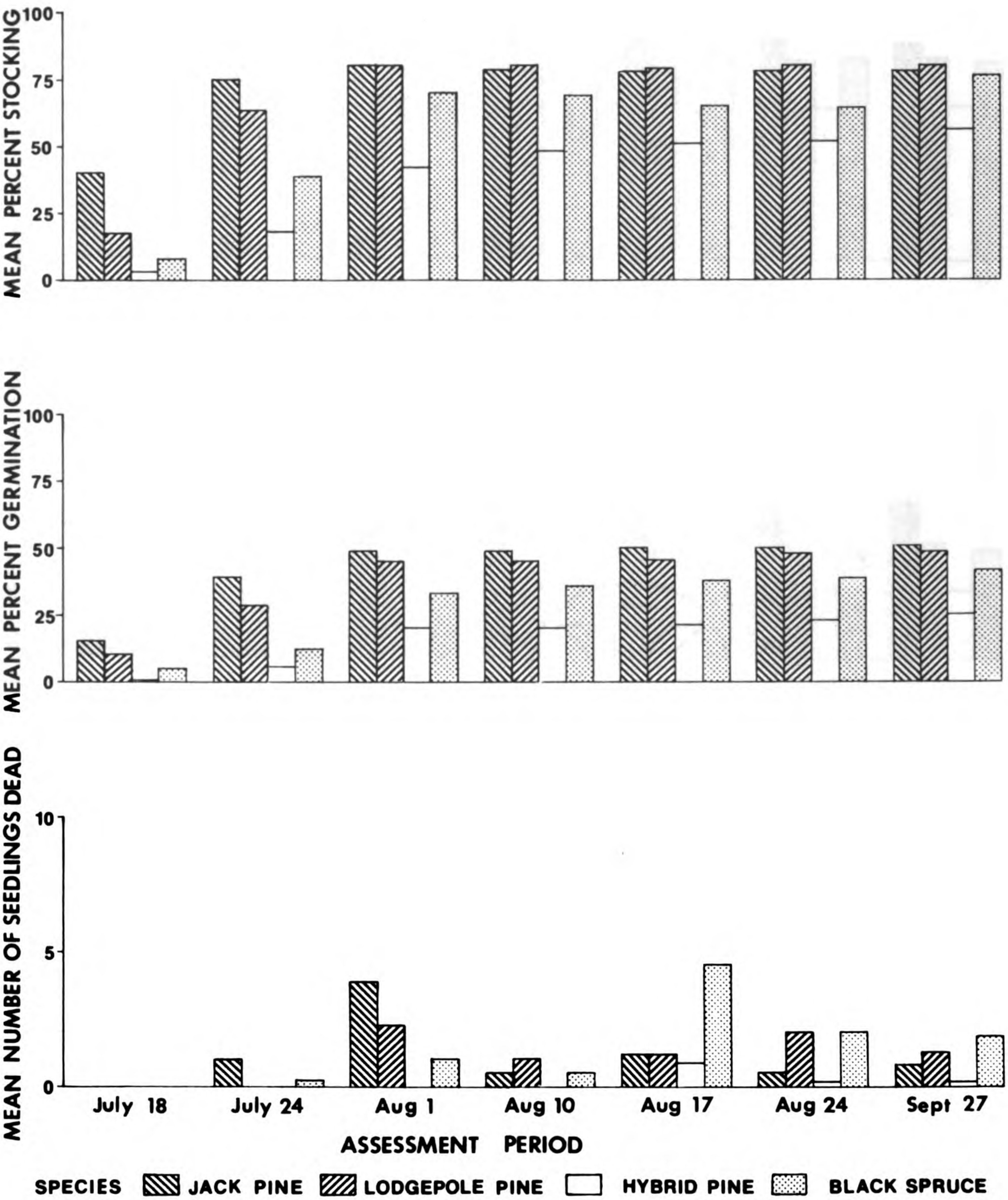

Figure 13. Stocking, germination and mortality of the three species and hybrid pine seeded in 25 scalps in the 1972 moist site.

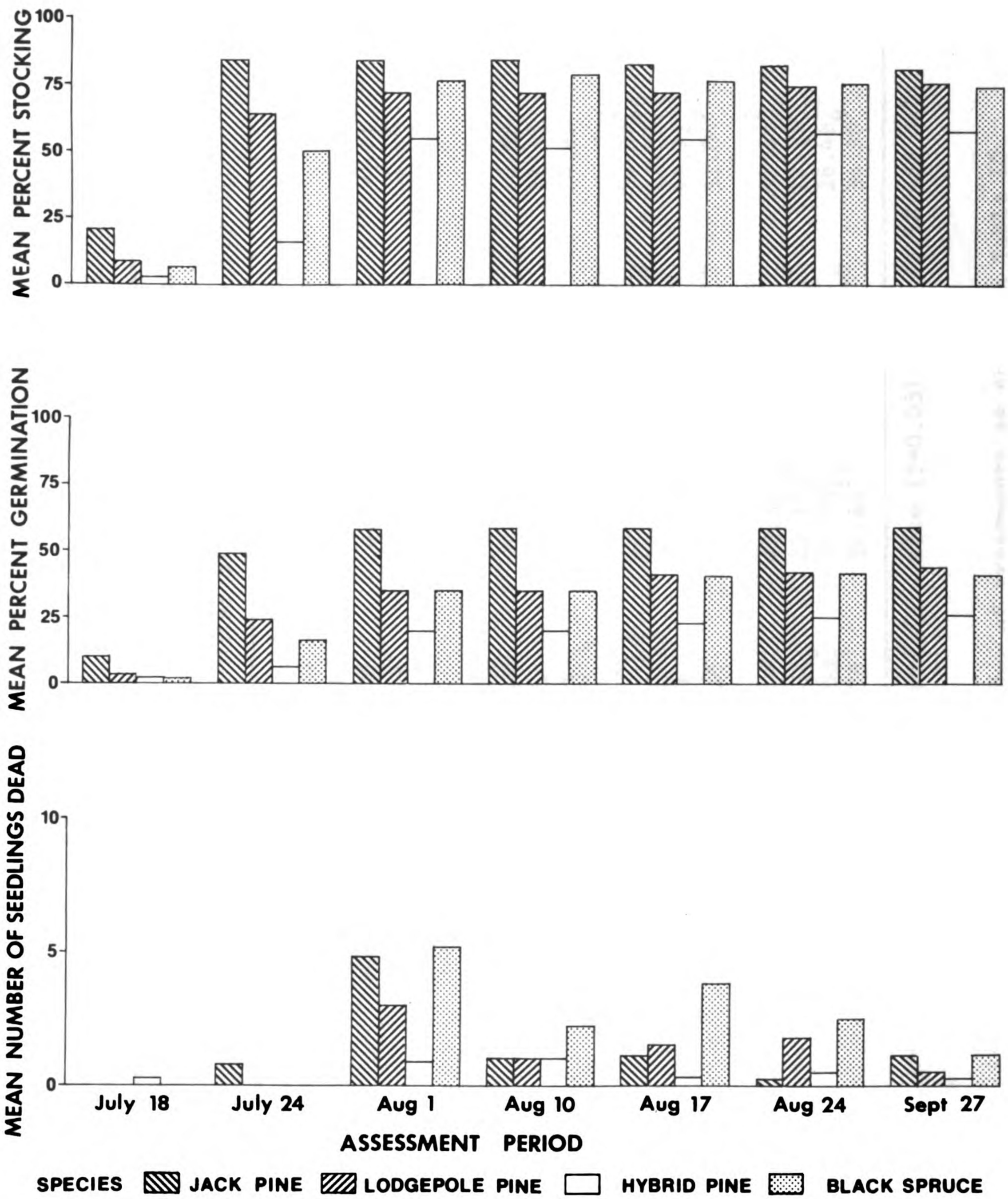

Figure 14. Stocking, germination and mortality of the three species and hybrid pine seeded in 25 scalps in the 1972 dry site.

Table 9. The effect of screening on germination of the three species and hybrid pine seeded on both moist and dry sites in 1972

Assessment period	Species	Percent germination: Moist site, Screened	Percent germination: Moist site, Non-screened	Percent germination: Dry site, Screened	Percent germination: Dry site, Non-screened
July 18	Jack pine	17.22*	13.85*	6.32*	8.23*
	Hybrid pine	0.00	0.00	0.27	0.81
	Lodgepole pine	5.19	1.99	4.01	1.66
	Black spruce	1.16	2.41	3.33	2.12
July 24	Jack pine	41.85*	36.71*	46.92*	47.39*
	Hybrid pine	4.89	4.37	7.51	4.86
	Lodgepole pine	36.80	19.99	29.34	18.61
	Black spruce	13.88	11.64	13.05	14.92
Aug. 1	Jack pine	52.40[3]	42.80[5]	55.80[1]	54.35[2]
	Hybrid pine	16.46[15]	16.79[14]	23.77[13]	15.35[16]
	Lodgepole pine	48.89[4]	33.59[8]	42.21[6]	25.72[12]
	Black spruce	38.83[7]	29.06[10]	28.19[11]	31.04[9]
Aug. 10	Jack pine	53.40[3]	43.31[6]	57.27[1]	55.85[2]
	Hybrid pine	19.42[15]	21.35[14]	25.94[13]	17.26[16]
	Lodgepole pine	52.00[4]	37.23[8]	48.00[5]	28.46[12]
	Black spruce	40.79[7]	30.66[11]	32.93[10]	34.30[9]

* Indicates significant treatment within a site (P=0.05) for July 18 and July 24 assessments.

[1, 2, ... 16] Indicates ranked order of treatments as shown in Table 10.

Table 9. Continued

Assessment period	Species	Percent germination: Moist site, Screened	Moist site, Non-screened	Dry site, Screened	Dry site, Non-screened
Aug. 17	Jack pine	53.40	44.39	57.76	56.33
	Hybrid pine	21.63	24.66	26.49	18.87
	Lodgepole pine	52.45	38.09	50.66	29.75
	Black spruce	42.41	31.83	33.73	35.11
Aug. 24	Jack pine	53.40	44.84	57.76	57.80
	Hybrid pine	22.70	25.17	27.01	20.46
	Lodgepole pine	53.33	38.98	52.00	30.64
	Black spruce	42.81	33.05	34.95	36.31
Sept. 27	Jack pine	53.90[4]	44.84[7]	57.76[2]	58.30[1]
	Hybrid pine	24.31[15]	28.61[14]	30.26[13]	20.96[16]
	Lodgepole pine	54.63[3]	39.43[8]	52.44[5]	31.98[12]
	Black spruce	46.46[6]	35.45[10]	34.95[11]	37.55[9]

1, 2, ... 16 Indicates ranked order of treatments as shown in Table 10.

Table 10. Test of significance based on Duncan's Multiple Range Test for germination by treatment and assessment date

Assessment date																	
Aug. 1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	B.
Aug. 10	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
Sept. 27	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	

T.

B. Treatments are ranked from High = 1 to Low = 16 for each assessment date as shown in Table 9.

T. Lines join treatments not significantly different (P=0.05).

The majority of seedspots were hard packed by the end of the growing season and there was very little erosion. A few seedspots became flooded periodically; however, this did not appear to affect germination or survival adversely.

Jack pine, lodgepole pine and black spruce germination commenced on July 15, 1972, approximately three weeks after seeding. Jack pine seeds germinated significantly faster than all other species and achieved near maximum levels one week before the other species (Figure 13 and Figure 14). Black spruce seed continued to germinate throughout the season. Hybrid pine seed, as in the 1971 trial, germinated slowly and only an extremely low percentage germinated in the first growing season. The germination percentages reported are corrected values. For each species, the highest germination in the cardinal temperature study was considered as 100 percent for field seeding. For example, jack pine had 81 percent in the laboratory study, thus only 81 per 100 sown, or 101 per 125 sown in the field, were capable of germinating. If 50 of the possible 101 seeds germinated, then the species germination reported would be 49.5 percent.

Mean soil moisture levels were consistently above 16.1 percent, and 20.5 percent (by weight), for the dry and moist sites respectively. Since field soil moisture levels never reached as low as those obtained in laboratory studies, even after a week of no precipitation (Figure 12), it is apparent that the selection of 1/3 atmosphere tension as field capacity was too high a tension level. Scrapings of the surface 2 mm of seedbed soil indicated that this upper horizon dried down to six percent moisture content or less at various times, particularly during the first three weeks after seeding.

Jack pine and lodgepole pine had the fastest rate of germination, whether scalps were screened or non-screened (Figure 13, Figure 14, Table 9).

Stocking was excellent for all species, except hybrid pine. Results were similar to those obtained in the 1971 seeding with the exception of black spruce which, at final assessment, had 76 percent stocking on the moist site (Figure 13) and 75 percent on the dry site (Figure 14). These percentages are extraordinarily high for the species and indicate that black spruce is capable of germinating and surviving on two widely different sites, if given a well-prepared receptive seedbed, adequate soil moisture and a lack of other climatic extremes.

Soil temperature data indicate daily maximum temperatures exceeded 27 C (80.5 F) throughout most of the growing season and were particularly high in the first few weeks after seeding (Table 8). Maximum temperatures were always one to several degrees higher on the dry site than on the moist site. Minimum temperatures were similar on both sites (Figure 12).

Cardinal temperature studies have shown that jack pine seed germinates well at temperatures above 26.7 C (80 F). Lodgepole pine and hybrid pine seed are much more temperature sensitive than jack pine seed. Both rate and percent germination are lower when temperatures exceed 26.7 C (80 F). According to Fraser (1970b) black spruce germinates well at temperatures above 26.7 C (80 F).

The author hypothesizes that the high temperatures experienced shortly after seeding made possible the more rapid germination of jack pine, whereas the other species germinated at lower levels at such high temperatures. Although black spruce germinated rapidly at higher temperatures in a constant temperature cabinet, it was unable to germinate rapidly in the field. This may be due to soil surface drying which reduced moisture contents below that necessary for the exceedingly small black spruce seed to germinate, yet it was sufficient to allow the much larger sized jack pine seed to germinate.

It is then conceivable that a period of prolonged drought or high temperatures would continue to limit the germination of black spruce, lodgepole pine and hybrid pine seed, yet jack pine seed would continue to germinate and survive. In this particular growing season, temperature maxima declined slightly in mid-July and rainfall was heavy and consistent (Table 8). Climatic normals presented in Table 11 for White River, Ontario, (50 miles to the south) and Hornepayne, Ontario (35 miles to the northeast) indicate that air temperatures experienced in the field were near normal but rainfall was above normal for all months except the late portion of June.

This hypothesis may also account for the variability in, and difficulty of obtaining successful black spruce regeneration by seeding. The studies in 1971 and 1972 indicate that jack pine can be seeded with greater probability of success than any of the other species. Lodgepole pine germinated and survived extremely well and indeed provided slightly higher stocking than jack pine. Due to its more critical temperature requirements for germination, lodgepole pine may be more difficult to regenerate under prolonged high temperature field conditions. Hybrid pine germination and stocking, both of which were lower than all other species, may follow the pattern established in 1971 and show an increase in the second year. However, its potential as an alternative species seems questionable because of its

Table 11. Thirty-year climatic normals for Canada Department of Transport weather stations near Manitouwadge

		Temperature C (F)*				
		June	July	August	September	October
Hornepayne	Max	20.2 (68.7)	23.2 (74.2)	21.3 (70.7)	15.4 (60.1)	8.7 (47.8)
	Min	6.8 (44.3)	9.3 (49.0)	7.7 (46.1)	4.0 (39.3)	-0.9 (30.2)
White River	Max	20.9 (70.1)	23.8 (75.3)	22.3 (72.6)	15.9 (61.0)	9.3 (49.0)
	Min	6.1 (43.0)	8.2 (46.9)	7.3 (45.2)	3.7 (38.8)	-1.7 (29.5)

	Precipitation cm (inches)**				
Hornepayne	7.51 (2.96)	6.57 (2.59)	6.85 (2.70)	8.63 (3.40)	5.48 (2.16)
White River	7.89 (3.11)	7.16 (2.82)	7.31 (2.88)	9.42 (3.71)	7.01 (2.76)

* Canada Department of Transport, 1968a.

** Canada Department of Transport, 1968b.

Figure 15. Seedlings from the 1971 and 1972 dry site field seeding trials (reduced x 2.5). Left to right: 18-month-old black spruce, hybrid pine, jack pine, lodgepole pine; right: 10-week-old lodgepole pine, black spruce, jack pine and hybrid pine.

Figure 16. Black spruce seedlings, from the dry site field seeding trials, (actual size). Left: 18-month-old; right: 10-week-old.

critical temperature requirements.

Mortality of all species was minimal. About 50 percent of those killed had been snipped-off just below the cotyledons by insects. Mortality of the other 50 percent can be attributed to flooding, soil surface drying, or failure of the hypocotyl to develop.

Measurements of seedlings removed from both the 1971 and 1972 seeding trials indicate slightly greater growth by jack pine than by the other pines of the same age, except on the 1971 dry site where the few surviving hybrid pine germinates produced greater top growth (Figure 15, Table 12). Growth of black spruce was considerably poorer and indicates that this species may be much more susceptible than the pines to extremes of climate. This poorer growth of black spruce, particularly root development (Figure 16), may account for the increased mortality experienced in the 1971 field seeding trial. Seedlings, such as pines, with larger root systems would be less susceptible to soil washing and root exposure than black spruce.

At no time in the 1972 study did site have a significant effect on germination. As mentioned previously, jack pine germinated significantly faster than the other species. Lodgepole pine germination rates became similar to those of jack pine, but not until the third assessment was made on August 1.

Screening placed over the seedspots increased germination, but this was found to be significant only for lodgepole pine on the dry site. There were no other main effects or interactions. (Table 9).

Results of the screening study were quite variable and to date are inconclusive. Screens did not significantly alter temperatures. The screens may have shaded the seedspots and may have intercepted precipitation. Based on the variable results, it appears that the screens slightly altered the microsite, but they certainly did not indicate a rodent population or problem.

Table 12. Growth measurements for seedlings extracted in August, 1972 from both the 1971 and 1972 field seeding trials

Date of seeding	Site	Species	Mean* top height mm	(inch)	Mean* length of longest root mm	(inch)
1971	Dry	Jack pine	30.2	(1.19)	154.6	(6.09)
		Hybrid pine	36.3	(1.43)	166.0	(6.54)
		Lodgepole pine	27.1	(1.07)	180.2	(7.09)
		Black spruce	16.4	(0.65)	58.5	(2.30)
1971	Moist	Jack pine	45.3	(1.78)	181.4	(7.14)
		Hybrid pine	21.7	(0.85)	101.7	(4.00)
		Lodgepole pine	23.9	(0.94)	142.4	(5.61)
		Black spruce	22.1	(0.87	69.3	(2.73)
1972	Dry	Jack pine	17.0	(0.67)	91.3	(3.59)
		Hybrid pine	14.3	(0.56)	48.1	(1.89)
		Lodgepole pine	13.8	(0.54)	64.5	(2.54)
		Black spruce	7.2	(0.28)	31.7	(1.25)
1972	Moist	Jack pine	18.0	(0.71)	67.4	(2.65)
		Hybrid pine	12.6	(0.50)	41.2	(1.62)
		Lodgepole pine	15.2	(0.60)	61.3	(2.41)
		Black spruce	8.7	(0.34)	26.1	(1.03)

* Mean of 10 seedlings.

CHAPTER V

SILVICULTURAL IMPLICATIONS OF RESEARCH RESULTS

Contrary to past seeding results reported in Ontario, black spruce seeds were found to germinate and seedlings survived on carefully prepared seedbeds, on a large cutover in a year of above normal precipitation. Many sources of variation occurred in the 1971 seeding which obscure comparisons between the 1971 and 1972 seeding trials. Nevertheless, black spruce seeds did germinate in both years and on both sites despite climatic and seedbed-preparation differences. The results indicate that black spruce requires a more carefully prepared seedbed than the pine species tested; they also verify reports that a humus and mineral soil mixture is desirable for germination and survival. Thus careful attention must be paid to seedbed preparation in order to obtain successful field germination of black spruce seed.

Both jack pine and lodgepole pine germinated and survived well in the 1971 and 1972 seedings, and on both site types. The two species are well suited to harsh cutover conditions and do not require as carefully prepared seedbeds as does black spruce. Based on the experimental results in both field and pot trials, there is little difference in the growth of the two pines or in their ability to survive. Field trials must be continued over several years to determine if any benefits can be obtained by substituting lodgepole pine for jack pine. At the seedling stage, jack and lodgepole pines would appear to be good substitutes for black spruce; however, hybrid pine appears less attractive because of its seed's inability to germinate satisfactorily in the year of seeding.

All field sites tested were deficient in phosphorus and potassium. Nitrogen was deficient in dry site soils, and in some pits sampled in the moist sites. The fertility pot trials indicated that significant increments in growth could be obtained by the addition of fertilizers to the field soils. Nutrient additions should be formulated to raise soil fertility levels to those prescribed by Wilde (1958) as Grade C, for pines, and Grade B for black spruce.

Black spruce seedlings were found to survive and grow in soils at moisture levels as low as 10 atmospheres suction. This indicates that survival is affected by factors other than soil moisture alone. The three pines tested grew better at high soil moisture levels than at low levels. Jack pine and lodgepole pine appear to be the best species for seeding on dry sites.

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APPENDICES

APPENDIX A

Details of seed origin and initial germination tests

Table 13. Details of seed origin and initial germination tests

Species	Location	Tree or stand	D.B.H. (cm)	Total height (m)	Age (years)	General remarks	% Germination	% Viability
Lodgepole pine	Marlborough, Alberta, Long. 117° 46'W Lat. 53° 42'N	1	30.0	21.3	97	Sandy podzol ridge 45.7 cm deep over glacial rubble	94.5	96.5
		2	27.2	20.4	91	Shallow podzol over stream gravel	85.5	89.0
		3	27.4	20.7	104	Shallow podzol over stream gravel	73.5	76.0
Hybrid pine	Fox Creek, Alberta, Long. 116° 54'W Lat. 54° 19'N	1	41.4	28.0	101	Fine silty sand luxuriant ground vegetation	60.5	64.0
Jack pine	Chapleau, Ontario, Long. 83° 25'W Lat. 47° 45'N	1	10.2-19.0	13.7-16.8	45	Deep sand outwash, immature podzol dense stand	75.5	76.3
		2	20.3-31.8	22.9-24.4	100-105	Deep sand outwash, immature podzol open grown stand	63.3	64.3
Black spruce	Ontario site region 3E					Sample from region-wide collection	99.0	99.0

% Germinability - Seeds germinated and developed to seedling in test period (21 days).

% Viability - % Germinability plus seeds germinated with a radicle or short hypocotyl.

APPENDIX B

Cardinal temperature study
7-, 14-, 21-, 28-day germination percent
means by species and population

Table 14. Cardinal temperature study: 7-day germination percent means by species and population

Temperature C (F)	Jack pine #1	Jack pine #2	Lodgepole pine #1	Lodgepole pine #2	Lodgepole pine #3	Hybrid pine
35.0 (95)	49	56	13	17	18	2
32.2 (90)	67	53	10	16	5	2
29.4 (85)	72	--	11	19	13	7
26.7 (80)	79	70	72	78	69	29
23.9 (75)	73	61	64	63	60	30
21.1 (70)	71	58	79	76	80	52
18.3 (65)	69	58	32	18	8	3
15.6 (60)	0	1	0	0	0	0
12.8 (55)	0	0	0	0	0	0
10.0 (50)	0	0	0	0	0	0
7.2 (45)	0	0	0	0	0	0

Table 15. Cardinal temperature study: 14-day germination percent means by species and population

Temperature C (F)	Jack pine #1	Jack pine #2	Lodgepole pine #1	Lodgepole pine #2	Lodgepole pine #3	Hybrid pine
35.0 (95)	51	58	31	35	25	4
32.2 (90)	73	58	24	29	15	4
29.4 (85)	73	--	19	23	18	8
26.7 (80)	79	70	73	82	73	41
23.9 (75)	76	62	75	67	66	37
21.1 (70)	77	60	90	81	88	75
18.3 (65)	79	66	80	81	57	73
15.6 (60)	65	60	63	63	36	41
12.8 (55)	24	40	0	4	0	0
10.0 (50)	0	0	0	0	0	0
7.2 (45)	0	0	0	0	0	0

Table 16. Cardinal temperature study: 21-day germination percent means by species and population

Temperature C (F)	Jack pine #1	Jack pine #2	Lodgepole pine #1	Lodgepole pine #2	Lodgepole pine #3	Hybrid pine
35.0 (95)	52	58	41	46	31	6
32.2 (90)	73	58	38	42	25	6
39.4 (85)	73	--	31	29	22	10
26.7 (80)	79	70	73	84	74	43
23.9 (75)	76	63	77	68	67	38
21.1 (70)	77	61	90	81	89	76
18.3 (65)	80	66	80	82	61	74
15.6 (60)	71	62	68	69	52	53
12.8 (55)	61	56	3	15	2	9
10.0 (50)	9	32	1	0	1	0
7.2 (45)	0	0	0	0	0	0

Table 17. Cardinal temperature study: 28-day germination percent means by species and population

Temperature C (F)	Jack pine #1	Jack pine #2	Lodgepole pine #1	Lodgepole pine #2	Lodgepole pine #3	Hybrid pine
35.0 (95)	52	58	51	56	35	8
32.2 (90)	73	58	54	51	37	8
29.4 (85)	73	--	38	32	25	11
26.7 (80)	79	70	74	85	74	43
23.9 (75)	76	63	78	69	68	38
21.1 (70)	77	61	90	81	89	77
18.3 (65)	81	67	81	82	63	75
15.6 (60)	74	62	68	70	57	54
12.8 (55)	68	57	5	19	2	11
10.0 (50)	26	49	4	0	2	1
7.2 (45)	0	0	0	0	0	0

APPENDIX C

Effects of soil moisture levels and site on the growth and tissue nutrient levels of seedlings grown in a greenhouse experiment

Table 18. Effects of soil moisture levels and site on lodgepole pine seedling growth

	Mean top height (mm)		Mean top weight (g)	
	Site			
Moisture level	Moist	Dry	Moist	Dry
1/3 atm	36.50[a,b]	44.70[a]	0.089[c]	0.140[a]
2 Atm	35.15[b]	33.80[b]	0.102[b]	0.089[c]
10 Atm	35.80[a,b]	30.20[b]	0.081[d]	0.066[c]

	Mean length of longest root (mm)		Mean root weight (g)	
	Site			
Moisture level	Moist	Dry	Moist	Dry
1/3 Atm	183.05[a]	157.05[b]	0.133[a]	0.184[a]
2 Atm	164.25[a,b]	147.35[b,c]	0.116[a]	0.113[a]
10 Atm	174.45[a,b]	128.55[c]	0.105[a]	0.105[a]

Treatments not having a common letter for each set of values are significantly different at the 5% level.

Table 19. Effects of soil moisture levels and site on hybrid pine seedling growth

	Mean top height (mm)		Mean top weight (g)	
	Site			
Moisture level	Moist	Dry	Moist	Dry
1/3 Atm	57.25[a]	51.95[a]	0.155[b]	0.160[a]
2 Atm	35.80[b]	32.80[b]	0.086[c]	0.074[e]
10 Atm	36.70[b]	31.40[b]	0.080[d]	0.070[e]

	Mean length of longest root (mm)		Mean root weight (g)	
	Site			
Moisture level	Moist	Dry	Moist	Dry
1/3 Atm	172.00[a]	180.20[a,b]	0.146[a]	0.103[a]
2 Atm	156.55[b]	134.50[c]	0.129[a]	0.107[a]
10 Atm	167.05[b]	132.90[c]	0.134[a]	0.081[a]

Treatments not having a common letter for each set of values are significantly different at the 5% level.

Table 20. Effects of soil moisture levels and site on jack pine seedling growth

	Mean top height (mm)		Mean top weight (g)	
	Site			
Moisture level	Moist	Dry	Moist	Dry
1/3 Atm	50.40[a]	45.80[a,b]	0.172[a]	0.130[b]
2 Atm	39.40[b,c]	36.20[c]	0.088[d]	0.077[e]
10 Atm	39.70[b,c]	32.13[c]	0.107[c]	0.065[f]

	Mean length of longest root (mm)		Mean root weight (g)	
	Site			
Moisture level	Moist	Dry	Moist	Dry
1/3 Atm	163.80[a]	162.05[a]	0.113[a]	0.130[a]
2 Atm	164.20[a]	149.15[a]	0.074[a]	0.155[a]
10 Atm	158.05[a]	142.13[a]	0.081[a]	0.084[a]

Treatments not having a common letter for each set of values are significantly different at the 5% level.

Table 21. Effects of soil moisture levels and site on black spruce seedling growth

	Mean top height (mm)		Mean top weight (g)	
	Site			
Moisture level	Moist	Dry	Moist	Dry
1/3 Atm	42.60[a]	29.95[b]	0.040[a]	0.030[b]
2 Atm	28.85[b]	18.72[c]	0.029[b]	0.016[c]
10 Atm	33.93[b]	11.69[c]	0.033[b]	0.029[b]

	Mean length of longest root (mm)		Mean root weight (g)	
	Site			
Moisture level	Moist	Dry	Moist	Dry
1/3 Atm	126.70[a]	73.95[b]	0.020[a]	0.016[a]
2 Atm	112.83[a]	81.28[b]	0.019[a]	0.014[a]
10 Atm	126.87[a]	82.31[b]	0.033[a]	0.014[a]

Treatments not having a common letter for each set of values are significantly different at the 5% level

Table 22. Effects of soil moisture levels and site on seedling foliage nutrient concentrations

		Nutrient concentration (% available)									
		Moist site					Dry site				
Species	Moisture level	N	P[8)]	K	Ca	Mg	N	P[8)]	K	Ca	Mg
Lodgepole pine	1/3 Atm	1.900		1.225	0.409	0.136	2.350		1.092	0.139	0.129
	2 Atm	1.908		0.847	0.287	0.137	2.282		0.792	0.162	0.111
	10 Atm	1.982		1.030	0.461	0.143	2.183		0.803	0.175	0.116
Hybrid pine	1/3 Atm	2.028		1.139	0.359	0.151	2.193		1.132	0.170	0.132
	2 Atm	1.925		1.111	0.345	0.137	2.148		0.821	0.181	0.116
	10 Atm	2.019		1.152	0.412	0.132	2.021		0.945	0.177	0.110
Jack pine	1/3 Atm	1.857		1.263	0.307	0.147	2.344		1.103	0.183	0.141
	2 Atm	1.680		0.971	0.439	0.138	2.135		0.793	0.181	0.123
	10 Atm	1.777		0.878	0.395	0.137	2.229		0.905	0.164	0.118
Black spruce	1/3 Atm	1.158		0.974	0.554	0.137	2.373		0.925	0.348	0.131
	2 Atm	1.885		0.716	0.591	0.127	2.265		0.341	0.313	0.115
	10 Atm	1.858		0.698	0.695	0.133	2.454		0.288	1.509	0.253

8) Results obtained are unreliable.

Table 23. Effects of soil moisture levels and site on seedling root nutrient concentrations

Species	Moisture level	Nutrient concentration (% available)							
		Moist site				Dry site			
		P[8]	K	Ca	Mg	P[8]	K	Ca	Mg
Lodgepole pine	1/3 Atm		0.782	0.658	0.209		0.716	0.200	0.080
	2 Atm		0.774	0.799	0.208		0.488	0.211	0.075
	10 Atm		0.756	1.073	0.240		0.555	0.292	0.071
Hybrid pine	1/3 Atm		0.707	0.830	0.227		0.897	0.491	0.177
	2 Atm		0.646	0.767	0.197		0.508	0.174	0.091
	10 Atm		0.526	0.766	0.193		0.598	0.414	0.070
Jack pine	1/3 Atm		1.030	0.719	0.239		0.659	0.303	0.102
	2 Atm		0.578	0.893	0.209		0.474	0.213	0.091
	10 Atm		0.709	0.827	0.230		0.534	0.188	0.057
Black spruce	1/3 Atm		0.488	0.596	0.236		0.439	0.389	0.128
	2 Atm		0.357	0.711	0.224		0.303	0.345	0.088
	10 Atm		0.403	0.654	0.215		0.263	2.047	0.272

8) **Results obtained are unreliable.**

APPENDIX D

Effects of soil fertility levels and site
on the growth and tissue nutrient levels
of seedlings grown in a greenhouse experiment

Table 24. Effects of soil fertility levels and site on lodgepole pine seedling growth

	Mean top height (mm)		Mean top weight (g)	
	Site			
Fertility level	Moist	Dry	Moist	Dry
Control	40.75^{a}	23.95^{b}	$0.145^{a,b}$	0.056^{c}
Low	38.65^{a}	35.77^{a}	0.125^{b}	$0.148^{a,b}$
High	40.90^{a}	44.83^{a}	$0.161^{a,b}$	0.191^{a}

	Mean length of longest root (mm)		Mean root weight (g)	
	Site			
Fertility level	Moist	Dry	Moist	Dry
Control	$233.95^{a,b}$	$207.95^{a,b}$	$0.287^{a,b}$	0.136^{c}
Low	239.40^{a}	$227.71^{a,b}$	$0.182^{b,c}$	0.332^{a}
High	$202.10^{b,c}$	172.96^{c}	$0.226^{a,b}$	$0.281^{a,b}$

Treatments not having a common letter for each set of values are significantly different at the 5% level.

Table 25. Effects of soil fertility levels and site on hybrid pine seedling growth

	Mean top height (mm)		Mean top weight (g)	
	Site			
Fertility level	Moist	Dry	Moist	Dry
Control	39.85[a]	24.75[b]	0.125[b]	0.043[c]
Low	41.90[a]	46.25[a]	0.134[a,b]	0.165[a,b]
High	50.02[a]	44.25[a]	0.178[a]	0.181[a]

	Mean length of longest root (mm)		Mean root weight (g)	
	Site			
Fertility level	Moist	Dry	Moist	Dry
Control	228.10[a.b]	190.70[c,d]	0.157[b]	0.110[b]
Low	236.55[a]	210.29[a,c]	0.149[b]	0.377[a]
High	198.80[b,c]	162.49[d]	0.177[b]	0.361[a]

Treatments not having a common letter for each set of values are significantly different at the 5% level.

Table 26. Effects of soil fertility levels and site on jack pine seedling growth

	Mean top height (mm)		Mean top weight (g)	
	Site			
Fertility level	Moist	Dry	Moist	Dry
Control	32.00[a,b]	26.10[b]	0.091[b]	0.046[b]
Low	38.85[a]	39.70[a]	0.145[a]	0.165[a]
High	36.50[a,b]	52.05[a]	0.158[a]	0.188[a]

	Mean length of longest root (mm)		Mean root weight (g)	
	Site			
Fertility level	Moist	Dry	Moist	Dry
Control	216.50[a,b]	199.15[b,c]	0.093[b]	0.101[b]
Low	232.75[a]	218.85[a,b]	0.181[b]	0.334[a]
High	194.55[b,c]	168.25[c]	0.169[b]	0.403[a]

Treatments not having a common letter for each set of values are significantly different at the 5% level.

Table 27. Effects of soil fertility levels and site on black spruce seedling growth

	Mean top height (mm)		Mean top weight (g)	
	Site			
Fertility level	Moist	Dry	Moist	Dry
Control	37.30[b,c]	22.85[d]	0.042[a]	0.016[a]
Low	41.10[b]	27.79[c,d]	0.045[a]	0.030[a]
High	55.25[a]	20.55[d]	0.074[a]	0.017[a]

	Mean length of longest root (mm)		Mean root weight (g)	
	Site			
Fertility level	Moist	Dry	Moist	Dry
Control	132.00[a]	94.25[b]	0.023[a]	0.012[a]
Low	140.55[a]	96.10[b]	0.016[a]	0.023[a]
High	154.80[a]	87.55[b]	0.033[a]	0.010[a]

Treatments not having a common letter for each set of values are significantly different at the 5% level.

Table 28. Effects of soil fertility levels and site on seedling foliage nutrient concentrations

Species	Fertility level	Nutrient concentration (% available)									
		Moist site					Dry site				
		N	P[9]	K	Ca	Mg	N	P[9]	K	Ca	Mg
Lodgepole pine	Control	1.528		0.842	0.409	0.178	1.534		1.503	0.280	0.173
	Low	1.751		1.505	0.483	0.174	1.527		0.938	0.210	0.183
	High	1.603		2.115	0.514	0.211	2.274		1.634	0.153	0.217
Hybrid pine	Control	1.537		0.852	0.418	0.144	1.362		0.875	0.327	0.168
	Low	1.385		1.292	0.339	0.161	1.321		0.891	0.253	0.194
	High	1.546		2.913	0.468	0.219	2.170		1.569	0.149	0.242
Jack pine	Control	1.778		0.929	0.488	0.164	1.460		0.691	0.238	0.157
	Low	1.549		1.112	0.411	0.158	1.256		0.885	0.164	0.169
	High	1.760		1.533	0.500	0.222	1.299		1.349	0.142	0.244
Black spruce	Control	2.041		1.213	0.617	0.151	1.693		0.817	0.565	0.161
	Low	1.783		1.276	0.593	0.158	1.819		0.911	0.421	0.168
	High	1.589		1.850	0.614	0.293	2.616		1.205	0.536	0.321

9) Results obtained are unreliable

Table 29. Effects of soil fertility levels and site on seedling root nutrient concentrations

		Nutrient concentration (% available)							
		Moist site				Dry site			
Species	Fertility level	P[9]	K	Ca	Mg	P[9]	K	Ca	Mg
Lodgepole pine	Control		0.810	0.848	0.213		0.481	0.302	0.123
	Low		0.907	1.091	0.243		0.582	0.449	0.157
	High		1.128	3.313	0.255		0.872	0.238	0.149
Hybrid pine	Control		0.672	0.692	0.184		0.461	0.318	0.143
	Low		0.734	0.724	0.204		0.679	0.170	0.117
	High		1.011	1.349	0.293		0.522	0.186	0.079
Jack pine	Control		0.676	1.104	0.236		0.423	0.211	0.099
	Low		0.604	1.076	0.230		0.896	0.284	0.152
	High		1.075	3.446	0.284		0.888	0.167	0.190
Black spruce	Control		0.721	1.059	0.170		0.617	0.575	0.124
	Low		0.508	0.994	0.162		0.669	0.370	0.131
	High		1.368	1.351	0.282		0.929	0.779	0.199

[9] Results obtained are unreliable

APPENDIX E

Soil surface temperature and moisture levels
at the 1972 seeding location

Table 30. Soil surface temperature and moisture levels at the 1972 seeding location

Date	Temperature C (F)*		Moisture content percent (by weight)**	
	Moist site	Dry site	Moist site	Dry site
June 24				22.0
26	31.6 (89)	34.4 (94)		
28	38.3 (101)	39.4 (103)	23.7	19.2
July 4	22.2 (72)	26.6 (80)	20.5	18.7
7	31.6 (89)	30.5 (87)	25.5	18.5
10	20.5 (69)	20.5 (69)	31.2	25.8
15			30.9	24.6
18	25.0 (77)		33.1	25.7
19			28.2	27.8
26	18.3 (65)	20.0 (68)	33.9	24.8
Aug. 6	28.3 (83)	26.6 (80)	29.5	16.1
10			35.8	20.9
18	21.6 (71)	21.0 (70)	36.7	30.4
21			44.3	29.7
25			30.7	26.3
29	23.3 (74)	31.6 (89)		
Sept. 4			27.5	20.3

* Soil surface temperature recorded by thermocouple.

** Soil moisture levels in upper 5 cm of soil determined gravimetrically.